National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

National Park Service Beach Nourishment Guidance

Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2012/581

ON THE COVER
Top: Canaveral National Seashore, Florida (NPS photograph)
Bottom Left: Golden Gate National Recreation Area, California (NPS photograph)
Bottom Right: Kemp's ridley sea turtle (*Lepidochelys kempii*), Gulf Islands National Seashore, Florida (NPS photograph)

National Park Service Beach Nourishment Guidance

Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2012/581

Kate Dallas

GSA Guest Scientist
kate_dallas@partner.nps.gov

Jodi Eshleman

National Park Service
Geologic Resources Division
200 Chestnut St.
U.S. Custom House, 3rd Floor
Philadelphia, PA 19147
jodi_eshleman@gmail.com

Rebecca Beavers

National Park Service
Geologic Resources Division
12795 West Alameda Parkway
Lakewood, Colorado 80228
rebecca_beavers@nps.gov

September 2012

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report was reviewed as informative scientific information by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from the Geologic Resources Division (http://www.nature.nps.gov/geology) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm).

Please cite this publication as:

Dallas, K. L., J. Eshleman, and R. Beavers. 2012. National Park Service beach nourishment guidance. Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2012/581. National Park Service, Fort Collins, Colorado.

NPS 909/114346, September 2012

Contents

Page

Contents (continued)

Contents (continued)

Contents (continued)

Figures

Figures (continued)

Tables

Acknowledgments

We thank Riley Hoggard (National Park Service; NPS), Bridget Lussier (Applied Technology & Management), Julia Brunner (NPS), Courtney Schupp (NPS), Tracy Rice (Terraqueous Management & Research Group), Mark Messersmith (U.S. Army Corps of Engineers, Charleston), Andrew Coburn (Western Carolina University), S. Jeffress Williams (U.S. Geological Survey, Emeritus) and many state agencies for your insightful discussions, recommendations and willingness to share previous studies and lessons learned. We thank Courtney Schupp (NPS) for providing the case study presented in Appendix B. The lead author of the report was supported through the Geological Society of America's (GSA) GeoCorps America Program with funding from the NPS Geologic Resources Division. Mike Cook (also a GSA scientist) did extensive research on state requirements. We gratefully acknowledge the many detailed reviews by NPS staff, subject matter experts, and external peers.

Introduction

The National Park System (NPS) incorporates 85 coastal park units, including national parks, seashores, lakeshores, recreation areas, monuments, preserves, historic sites, and memorials. These areas contain over 19,000 km (12,000 mi) of shoreline, iconic American features, and a wide variety of geological, biological, and cultural resources. To protect and preserve National Park coastal resources, a clear approach to coastal sediment management based on sound coastal science and engineering is needed.

Purpose

This manual is intended to be used as guidance by NPS staff to better plan and manage beach nourishment projects when beach nourishment has been determined to be consistent with NPS Management Policies. This manual provides tools for resource managers to interface with partners that are completing technical designs and outlines best management practices that can be utilized to avoid or minimize potential adverse impacts. These tools and practices provide a consistent approach to proposed beach nourishment projects, but also contain the flexibility for different outcomes as appropriate based on specific park conditions and mandates. An informed, unified approach is necessary to protect coastal resources and adaptively manage these locations for future generations, especially in the face of weather variability and directional climate change. This guidance focuses on managing shoreline and nearshore sediment nourishment projects, but does not provide detailed information on technical design for projects. Project design should be tailored to individual project goals and site conditions, and requires the expertise of a professional specializing in this type of work.

Coastal structures (seawalls, groins, breakwaters, jetties, etc.) and dredging also are not addressed in this manual. However, many of the best management practices presented can be applied to these activities. Coastal structures and dredging can have potentially significant consequences for coastal ecosystems and require professional consultation.

The information in this manual was compiled from federal and state regulations, peer-reviewed and other publications, best management practices, other agency requirements, NPS regions for which extensive information was available, and experience with past projects. Because of the diversity of park units, the topics addressed in the manual will not always apply for a site-specific project. These topics present a starting point for discussion related to beach nourishment within the NPS and discussion with other agencies and partners. The suggested actions provide useful information to parks considering, analyzing, and/or developing planning documents that include beach nourishment.

Topics Covered

Topics addressed in this report include:

- Federal and state regulations;
- Existing NPS regulations and policy;
- General project design considerations;
- Sediment properties for beach nourishment;
- Nearshore sediment placement;
- Offshore borrow sources;
- Physical and biological monitoring; and
- Beach nourishment case studies.

Disclaimer

The information contained within this document is intended only to improve the internal management of the NPS. It does not replace or supplant applicable laws, regulations, or other authorities. This document does not create new NPS policy; instead it provides guidance for implementing existing NPS policy. It is not intended to, and does not, create any right or benefit, substantive or procedural, enforceable at law or equity by a party against the United States, its departments, agencies, instrumentalities or entities, its officers or employees, or any other person.

NPS Policy Considerations

The 2006 NPS *Management Policies* (NPS 2006) provide important considerations for evaluating when beach nourishment should, or should not, take place in a park unit. In some park areas, the resources and processes function naturally. In other areas, human-caused impacts may require some degree of restoration or mitigation. These situations, and how the relevant policies apply to proposed beach nourishment projects, are explained below.

Preservation of Natural Systems

In parks with "natural shoreline processes (such as erosion, deposition, dune formation, overwash, inlet formation, and shoreline migration)," these processes "will be allowed to continue without interference" (NPS *Management Policies* § 4.8.1.1, 2006).

The policies do allow intervention in natural geologic processes in certain situations, specifically when:

- "Directed by Congress;
- Necessary in emergencies that threaten human life and property;
- There is no other feasible way to protect natural resources, park facilities, or historic properties; or
- Intervention is necessary to restore impacted conditions and processes, such as restoring habitat for threatened or endangered species" (NPS *Management Policies* § 4.8.1, 2006).

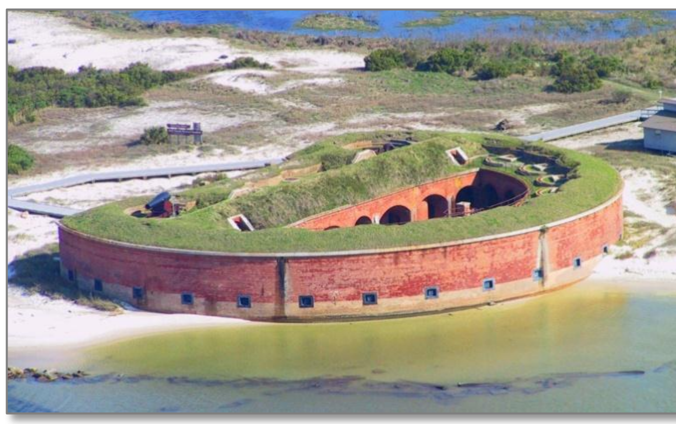

Figure 1. Erosion currently threatens historic Fort Massachusetts in Gulf Islands National Seashore, Mississippi. A restoration plan calls for sediment placement to supplement the eroded shoreline and help stabilize the foundation of the fort (Photograph by Bob Webster).

Beach nourishment is a type of intervention. Therefore, any beach nourishment proposed in park areas with natural shoreline processes must meet one or more of the above requirements to be deemed compatible with § 4.8.1 and § 4.8.1.1. This determination must utilize the results of any applicable scientific research, as required by NPS *Management Policies* § 2.1.2 (NPS 2006) (also see 16 U.S.C. § 5936). Additionally, any sediment placement shall be carried out in a way that ensures that park resources and values remain unimpaired, in order to comply with the NPS Organic Act, 16 U.S.C. § 1, and with NPS *Management Policies* § 1.4.2 (NPS 2006).

Other policies potentially relevant to beach nourishment proposals require that park landscapes "disturbed by natural phenomena, such as landslides, earthquakes, floods, hurricanes, tornadoes, and fires, will be allowed to recover naturally" unless manipulation (which includes beach nourishment) is necessary to:

- Mitigate for excessive disturbance caused by past human effects;

- Preserve cultural and historic resources as appropriate based on park planning documents; or
- Protect park developments or the safety of people.

(See NPS *Management Policies* § 4.1.5; also see NPS *Management Policies* § 4.4.2.4).

Restoration of Human-Disturbed Systems

Where human activities or structures have altered coastal dynamics, ecosystems, tidal regimes and sediment transport rates (e.g. Figure 1), the applicable NPS policy is different than the policy explained in the previous section. Activities and structures that alter shoreline processes include structures constructed both parallel (seawalls, breakwaters, revetments, bulkheads) and perpendicular (jetties, groins) to the shoreline, dredged harbors and navigation channels, and dredging or disposal of sediments within and beyond the littoral system. In these situations, the NPS policy is to investigate, in consultation with appropriate state and federal agencies, alternatives for "mitigating the effects of such activities or structures and for restoring natural conditions" (NPS *Management Policies* § 4.8.1.1, 2006). NPS restoration actions in human-disturbed areas seek to return the area to the "natural conditions and processes characteristic of the ecological zone in which the damaged resources are situated," (NPS *Management Policies* § 4.1.5; also see § 4.4.2.4, 2006). Beach nourishment to restore shoreline processes, areas disturbed by sediment extraction, and habitat, is an example of this policy (e.g. Figure 2). Throughout the restoration process the NPS will comply with all local, state, and federal laws and regulations.

Figure 2. Beach nourishment was implemented at Assateague Island National Seashore, Maryland to mitigate for some of the sediment lost from the beach since construction of the Ocean City Inlet jetties (Photograph by the U.S. Army Corps of Engineers).

Wetland Policy

NPS wetland protection policies are found in NPS *Management Policies* § 4.6.5 (NPS 2006). NPS Procedural Manual (P.M.) #77-1: Wetland Protection (NPS 2012c) establishes procedures for implementing these policies. Projects that involve sediment restoration in the intertidal zone are subject to NPS wetland protection policies and procedures because estuarine or marine intertidal zones (including beach areas between the extreme high and extreme low spring tidal elevations) are defined as wetlands under P.M. #77-1.

Figure 3. Prisoner's Harbor on Santa Cruz Island, Channel Islands National Park, California (Photograph by K. Noon).

The NPS has a “no net loss of wetlands” policy and strives to achieve a net gain of wetlands through restoration (NPS *Management Policies* § 4.6.5, 2006). Where wetlands have been degraded due to previous or ongoing human actions (e.g. Figure 3), the NPS will, to the extent practicable, restore them to pre-disturbance conditions. For new activities, that are either located in or otherwise could have adverse impacts on wetlands, the NPS will employ the following sequence:

- Avoid adverse wetland impacts to the extent practicable;
- Minimize impacts that cannot be avoided; and
- Compensate for remaining unavoidable adverse wetland impacts by restoring wetlands that have been previously destroyed or degraded.

Compensation for wetland impacts or losses requires that *at least* one acre of wetlands be restored for each acre destroyed or degraded (NPS *Management Policies* § 4.6.5, 2006). Greater than 1:1 compensation may be required when the wetlands being impacted are of high quality or exceptional value, when it will take a number of years for the restored site to become fully functional, or when the likelihood of full restoration success is unclear (P.M. #77-1§ 5.2.3). All actions proposed by the NPS that have the potential to cause adverse impacts on wetlands require NEPA compliance. If the action will result in adverse impacts on wetlands, a Wetland Statement of Findings must be prepared, circulated for public review and comment, and approved in accordance with NPS wetland protection procedures (P.M. #77-1§ 5.3.4 and 5.3.5).

Wetland Excepted Actions

Section 4.2 of P.M. #77-1 addresses actions that *may* qualify as “excepted” from the Wetland Statement of Findings and wetland compensation requirements (P.M. #77-1 § 5.2.3, 5.3.4 and 5.3.5). Section 4.2.1 (h) states that actions designed specifically for the purpose of restoring degraded (or completely lost) natural wetland, stream, riparian, or other aquatic habitats or ecological processes may be excepted. For purposes of this exception, "restoration" refers to reestablishing environments in which natural ecological processes can, to the extent practicable, function at the site as they did prior to disturbance. Proposed restoration actions that will result in a net loss of wetland habitat cannot be excepted under Section 4.2.1 (h).

For an action to be excepted from the Wetland Statement of Findings and compensation requirements, the conditions and best management practices (BMPs) referred to in P.M. #77-1 Section 4.2.2 must be satisfied. If one or more of these conditions or BMPs are not met, then the action reverts to full compliance with P.M. #77-1. Exceptions do not imply exemption from the Clean Water Act, Section 7(a) of the Wild and Scenic Rivers Act, Section 10 of the Rivers and Harbors Act, the Endangered Species Act, the National Environmental Policy Act (NEPA), or other laws, regulations, or procedures governing NPS activities.

If a project is determined to qualify as an “excepted action,” then wetland analyses are addressed in the NEPA compliance document. Examples of analyses include wetland delineations, impacts and benefits of the proposed actions to wetland physical and biological functions, maps and acreages of existing versus restored wetlands (by wetland type), sediment composition, soil type, grain size and color analyses, contaminants analyses, and effects on wetland and wetland-dependent flora and fauna. For projects that deal with intertidal wetland habitat, the extreme high and extreme low spring tidal elevations should be used to define the boundaries and acreages of wetlands. The NEPA compliance documentis also the place to address compliance with other requirements of P.M. #77-1, including explanations of avoidance and minimization of wetland impacts to the extent practicable and explanation of why the project was determined to qualify as an "excepted action."

Floodplain Policy

The NPS will manage for the preservation of floodplain values and minimize potentially hazardous conditions associated with flooding. Specifically, NPS *Management Policies* § 4.6.4 (2006) states the NPS will:

- Protect, preserve, and restore the natural resources and functions of floodplains;
- Avoid the long- and short-term environmental effects associated with the occupancy and modification of floodplains; and
- Avoid direct and indirect support of floodplain development and actions that could adversely affect the natural resources and functions of floodplains or increase flood risks.

When it is not practicable to locate or relocate development or inappropriate human activities to a site outside and not affecting the floodplain, the NPS will:

- Prepare and approve a Floodplain Statement of Findings, in accordance with procedures described in D.O. #77-2: Floodplain Management;
- Use nonstructural measures as much as practicable to reduce hazards to human life and property while minimizing the impact to the natural resources of floodplains; and
- Ensure that structures and facilities are designed to be consistent with the intent of the standards and criteria of the National Flood Insurance Program.

Revegetation and Landscaping

Any surplus soils or sediments from construction activities within the park may be used for the restoration of other degraded areas in the park, if it is determined that the use of the in-park source will not significantly affect cultural or natural resources or ecological processes (NPS *Management Policy* § 9.1.3.2, 2006). Soils or sediments imported from inside or outside park boundaries must be:

- Compatible with existing soils or sediments;
- Free of undesired seeds and organisms; and
- Fulfill the horticultural requirements of plants used for restoration.

Borrow Pits and Dredge Spoil Areas

Parks should use existing borrow sites or create new sites in the park only after developing and implementing a park-wide borrow management plan that addresses the cumulative effects of borrow site extraction, restoration, and importation. NPS *Management Policy* § 9.1.3.3 (2006) requires that materials from borrow pits, quarries, and other clay, stone, gravel, or sand sources on NPS lands, including submerged lands, will be extracted and used only:

- By the Park Service or its agents or contractors;
- For in-park administrative uses;
- After compliance with other applicable federal, state, and local requirements; and

- After compliance with the NEPA and National Historic Preservation Act (NHPA), including written findings that:
    - Extraction and use of in-park borrow materials does not or will not impair park resources or values;
    - It is the park's most reasonable alternative based on economic, environmental, and ecological considerations; and
    - No outside sources are reasonably available.

Dredged material may be used for beach nourishment or another resource management activity only if the superintendent first finds that the proposed nourishment or activity will not impair park resources and values and that the proposed activity is consistent with park planning documents (NPS *Management Policies* § 9.1.3.3, 2006). The development of new dredge spoil areas or borrow pits, or the expansion of existing ones, will be analyzed through the NEPA and NHPA processes. In addition, dredging and/or placement activities must meet the requirements of appropriate laws, regulations, executive orders, and related guidance, including, but not limited to, the Endangered Species Act, P.M. #77-1, D.O. #77-2, and sections 401 and 404 of the Clean Water Act.

Biological Resource Management

The National Park Service will maintain all plants and animals native to park ecosystems by (NPS *Management Policies* § 4.4.1, 2006):

- Preserving and restoring the natural abundances, diversities, dynamics, distributions, habitats, and behaviors of native plant and animal populations and the communities and ecosystems in which they occur;
- Restoring native plant and animal populations in parks when they have been extirpated by past human-caused actions; and
- Minimizing human impacts on native plants, animals, populations, communities, and ecosystems, and the processes that sustain them.

Native species are defined as all species that have occurred, now occur, or may occur as a result of natural processes on national park lands (NPS *Management Policies* § 4.4.1.3, 2006).

Legal Authority and Jurisdiction

A new reference manual has been developed to help NPS coastal park managers understand their legal and regulatory authorities. For jurisdictional guidance on a broad array of ocean and coastal topics see the Ocean and Coastal Park Jurisdiction Reference Manual #39-1 (NPS 2011).

Sediment Properties for Beach Nourishment

Sediment used for beach nourishment (Figure 4) should ideally be indistinguishable from native site sediment in terms of color, shape, size, mineralogy, compaction, organic content, and sorting. However, typically fill material does not exactly match the native sediment and a compatibility analysis is necessary to consider the similarity. This section presents factors that are used to assess sediment compatibility, including grain size, overfill factor, color, mineralogy, organic content, sediment contamination, and foreign matter.

Figure 4. Close-up image of beach sand, Golden Gate National Recreation Area, California (Photograph by P. Barnard).

Grain Size Compatibility

Sediment grain size is the single most important borrow material characteristic (Gravens et al. 2008). The grain size will affect the shape of the nourished beach, the rate at which fill material is eroded from the project, and the biological habitat. Coarse sediments will provide greater resistance to erosion, but may reduce recreational value to users of the beach or impact biological habitat, such as sea turtle nesting ability. The goal for nourishment is to choose sediment that best matches the native material of the beach to help reduce any unintended consequences that could result from modification.

To analyze for grain size, the native beach should be sampled throughout the length and width of the project area and include samples collected along cross-shore transects from the berm crest (or mean high water line) to a water depth corresponding to the position of the typical storm bar (Gravens et al. 2008). The purpose of sampling across the beach and into the nearshore is to capture the zone of active sediment processes. If cross-shore composites exhibit a wide range of median grain size and standard deviation values, an alongshore composite should be calculated for the entire project domain to reduce the variability (Gravens et al. 2008). All sediment samples should be taken from the surface to some predetermined depth and then mixed thoroughly before analysis to ensure representative sediment sampling. Subaqueous borrow areas should be sampled for grain size through physical sampling, such as coring, in a similar manner to that described for the native beach.

Grain size compatibility between borrow and native sediment is determined by comparing the grain size distributions (sand grain frequency, mean and median grain size, and standard deviation). Grain size characteristics are quantified based on sieve analyses of samples, from which particle size distribution curves can be graphed (Figure 5). Table 1 presents information on U.S. standard sieve sizes.

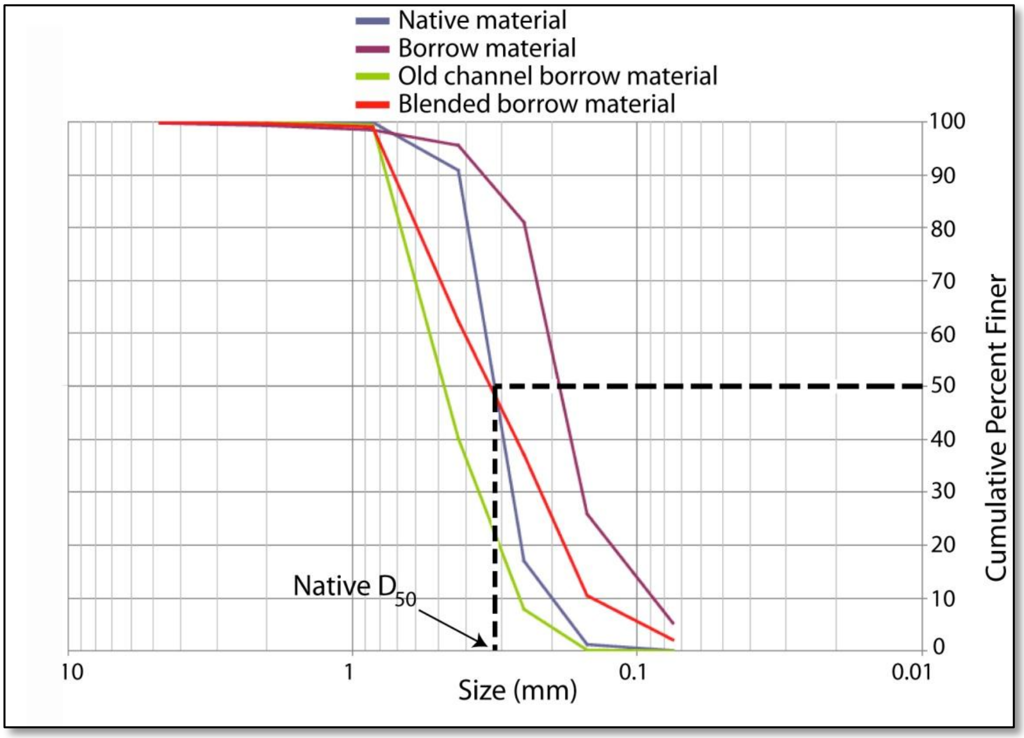

Figure 5. Grain size distribution curves from a restoration project in Gulf Islands National Seashore, Mississippi (Figure adapted from USACE 2010a).

Table 1. U.S. standard sieve sizes. Information from King and Galvin (2002).

U.S. Standard Sieve	Opening (mm)	Unified Soil Classification System
Greater than 12 in.	Greater than 300	Boulder
3 in. to 12 in.	75 to 300	Cobble
¾ in. to 3 in.	19 to 75	Coarse Gravel
#4 to ¾ in.	4.75 to 19	Fine Gravel
#10 to #4	2 to 4.75	Coarse Sand
#40 to # 10	0.425 to 2	Medium Sand
#200 to # 40	0.075 to 0.425	Fine Sand
#230 to # 200	0.0625 to 0.075	Fine-Grained Soil

The mean and median grain sizes are often used to describe the central tendency of the distribution. The median grain size diameter (D_{50}) is the diameter for which 50 percent of the sediment, by weight, has a smaller diameter. This can be estimated graphically from the particle size distribution curve (Figure 5). The standard deviation is a measure of the spread of the distribution around the mean. The range of grain sizes in the sample is also very important in characterizing the sediment. For example, a sample with a D_{50} of 0.3 mm and a range of 0.01 mm to 1.0 mm will look and act much different than a sample with a D_{50} of 0.3 mm and a range of 0.26 to 0.34 mm. King and Galvin (2002) present methods to estimate the mean sediment diameter and standard deviation from statistics of the particle size distribution.

Beach nourishment projects should use fill material with a composite grain size distribution similar to that of the native beach material. Ideally, the median size of the borrow sediment should not be less than the median of the native material and the spread of sizes in the borrow distribution should not exceed that of the native sediment (King and Galvin 2002). However, this is not always possible due to limitations in available borrow sites or incorporation of beneficial reuse sediment. On severely eroded beaches it is possible that the native distribution could be skewed toward the coarse sediments if the fines (silts and clays) have been eroded away (King and Galvin 2002). As a general recommendation, suitable material will have grain sizes that range from fine to very coarse sand with limited amounts (less than 10%) of very fine sand, silt, and clay. Sediment with less than 10% fines may help reduce turbidity and biological impacts to beach fauna (see Turbidity section) (Greene 2002). Excessive coarse material and shell hash should also be avoided because it can alter habitat characteristics and impair shorebird feeding (Peterson et al. 2006). The U.S. Army Corps of Engineers' Coastal Engineering Manual (CEM) (Gravens et al. 2008) recommends limits on grain size variation between native and borrow sediments (Table 2).

Table 2. U.S. Army Corps of Engineers' Coastal Engineering Manual recommended grain size compatibility limits (Gravens et al. 2008).

Native Median Grain Diameter	Compatible Borrow Median Grain Diameter
> 0.2 mm	within ± 0.02 mm
0.15–0.2 mm	within ± 0.01 mm
< 0.15 mm	at least as coarse as native

Some states, such as Florida and North Carolina, have detailed, quantitative requirements regarding sediment compatibility (Table 3). North Carolina also has state regulations regarding sediment compatibility sampling techniques. These requirements can be used as general guidelines for beach nourishment projects in other states. However, it is important to consider the native sediment size carefully when reviewing other state regulations, since these were developed for the native sediment in that specific state. Parks in other states should check with the lead coastal management agency in their state (see Appendix A) for any relevant requirements and adhere to the recommendations outlined in this report for consistency and best management practices. Appendix A provides information related to state beach nourishment requirements and policies.

Table 3. Florida and North Carolina state requirements for beach nourishment sediment. Requirements are from the Florida Administration Code (2001) and North Carolina Administration Code (2007).

State	Particle Size Range (mm)	Allowable % Silt, Clay, Colloids (Passing #230 Sieve)	Allowable % Fine Gravel (Retained on #4 Sieve)	Allowable Coarse Material	Dredge Material Allowable % Fines (Passing #230 Sieve)	Carbonate Content
North Carolina*	n/a	% by weight of native beach plus additional 5%	% by weight of native beach plus additional 5%	% by weight of native beach plus additional 5%	up to 10% by weight	% by weight of native beach plus additional 15%
Florida	0.062–4.76	5% by weight or less	5% by weight or less	% material retained on 3/4 inch sieve cannot exceed % on native beach	up to 10% by weight (10%–20% for nearshore placement)	must not result in cementation

*Note – As of May 2012, North Carolina has included these requirements into state law, but has not integrated them into the state's federally approved coastal management program.

Overfill Factor Compatibility

Typically, the design of beach fill projects aims to compensate for the grain size differences between borrow sand and native sand by overfilling with borrow sand and assuming that a portion of the fine material will wash out by wave action (King and Galvin 2002). The overfill factor is used to roughly estimate the volume of fill material needed to produce a unit volume of material on the native beach after grain sorting losses (Gravens et al. 2008). For example, an overfill factor of 1.2 indicates that 120 m^3 (or yd^3) of fill sediment must be placed to yield 100 m^3 (or yd^3) of residual fill on the beach. Expressed in another way, this means that 1/1.2 = 83% of the borrow material is expected to remain as residual beach fill. The overfill calculation provides only an approximate volume estimation and should not be used in the final design process for volume calculations because it does not take into account any coastal processes (Gravens et al. 2008).

The overfill factor can also be used to assess the general suitability of fill material or to compare the relative merits of different borrow sites. The overfill factor is usually calculated using the Krumbein-James technique (Gravens et al. 2008). Dean (1974) offers another method for computing the overfill factor, which typically yields lower estimates of the overfill factor. The CEM presents a graphical method of calculating the overfill factor from mean and standard deviation values of the native and borrow sediments (Gravens et al. 2008).

The CEM (Gravens et al. 2008) recommends an overfill factor within the range of 1.00 to 1.05, but acknowledges that this is very difficult to achieve. (A value of 1.00 indicates direct compatibility, while values higher than 1.00 indicate greater non-compatibility.) A broader range of 1.0 to 1.5 was identified as satisfactorily compatible in the EA of the West Ship Island North Shore Restoration project in Mississippi (USACE 2010a). However, post-nourishment monitoring efforts at another project in Morehead City, North Carolina found that sediment with an overfill factor of 1.4 was non-compatible for local beaches (Bodge et al. 2006). In this instance the non-compatible material contained clay and high fractions of silt and large shells. A similar overfill factor, however, may be acceptable for another project if the grain size distributions (sand grain frequency, mean and median grain size, and standard deviation) of the native and borrow materials are similar. The overfill factor is only one factor used to assess sediment compatibility, and it is important to consider all factors before making a final compatibility decision.

Sediment Color Compatibility

Borrow material should be as close as possible in color to the native sediment to limit visual and biological impacts after placement. A change in sediment color can alter the sediment's temperature and affect organisms living in or utilizing the sediment. For example, sand temperature influences the reproductive success of many species, including horseshoe crabs (Avissar 2006) and sea turtles (Crain et al. 1995). (In addition to color, sand temperature is also dependent on the mineralogy of the sediment.) A change in beach color can also impact visitor enjoyment.

Figure 6. Natural sediment variability offshore Golden Gate National Recreation Area, California (Photograph by P. Barnard).

Sediment color is often described using the Munsell color chart (Munsell Color 2010). In the Munsell system sediment color is determined visually by comparing the sediment to the Munsell chart and identifying a matching color chip. Colors are measured along three different dimensions: hue, value (lightness or darkness), and chroma (departure from grey) and are recorded in the order of hue followed by value/chroma, such as 10YR 4/6 (Munsell Color 2010). Since moisture affects color, it can be useful to record color twice, once dry, and once moist. In some cases interstitial water contained in the borrow sample can make the material appear darker than the dry sediments, so it is recommended to wash a few samples before making the moist color determination (FDEP 2010).

Florida regulates color compatibility and requires that fill "be similar in color" to native beach sediment (FAC 2001). In Florida, fill material can be expected to lighten one Munsell value once placed on the beach and dried by the sun (FDEP 2010). However, darker or tanner colored sands in other states may undergo more drastic lightening when dried (e.g. Figure 6). Shell content can also influence the overall color of the sediment and will also likely lighten one Munsell value once dried. Some sediment may not lighten in the sun (i.e. iron stained sediment), so the source of the color of the sediment should be taken into account when determining color compatibility (FDEP 2010).

Composite Mineralogy

The mineralogy should be very similar between the fill and native material. Mineralogy affects sediment temperature, compaction, and moisture content, all of which can impact biological resources and physical processes. In most places sand-sized sediment is predominantly composed of quartz particles with lesser amounts of other minerals such as feldspar (Gravens et al. 2008). Some locations may also have a dominant amount of calcium carbonate that is usually of organic origin. To avoid cementation of the beach, calcium carbonate content of fill material should be limited. In North

Carolina, the composite mineralogy of the borrow material must be "similar to the mineralogy" of the native beach and the carbonate content in borrow material may not exceed the carbonate content of the native beach by more than 15% (NCAC 2007). In Florida, the carbonate content in the borrow sediment must not result in cementation of the beach (FAC 2001). Projects in other states should consult with the lead coastal state agency on any mineralogy requirements (see Appendix A for a list of state agencies).

Organic Content

Fill material should have similar organic content as the native beach. The organic content in sediment can greatly affect plant and animal populations. For example, the success of incubating turtle eggs can be reduced when the organic content of the fill material is different from the natural beach (Greene 2002). Maintaining the same organic content is also important because organic material supplies nutrients to benthic organisms. In high-energy environments, such as beaches, organic matter consists mainly of decayed macroalgae, feces, and animal remains (Thayer et al. 2003). Measurement of organic content requires destruction of the organic matter via chemicals or heat. The carbon is then converted to carbon dioxide and measured directly or indirectly. See Schumacher (2002) for more information on determination of organic content in sediment.

Sediment Contamination

Fill material must be substantially free of harmful chemical contaminants. Sediment is usually characterized as substantially free of contaminants if it is composed entirely of sand, gravel, or other inert material, and is found in areas of high current or wave energy (Moffatt & Nichol 2006). Chemical contaminants are usually associated with silt and clay-sized particles as well as organic substances. The likelihood for contamination may also be based on previous chemical testing of sediments from the same vicinity and/or proximity of the fill material to contaminant sources or preindustrial age deposits (Science Applications International Corporation 2007).

The United States Environmental Protection Agency (USEPA) has physical and chemical standards for sediments that will be placed in marine environments. Some states have adopted standards that are more rigorous than the USEPA standards. In addition, in order to preserve and protect park resources, parks may need to develop or adopt more stringent standards. For example, Gateway National Recreation Area has developed draft sediment standards for use in protection, restoration and maintenance projects. The draft standards exceed USEPA and New York Department of Environmental Quality standards. A higher standard has been deemed necessary by the park to protect and preserve park resources unimpaired. Further information on sediment chemical contamination can be found in the *Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. – Testing Manual* (USEPA and USACE 1998).

Foreign Matter

Fill material must be free of trash, debris, and large pieces of organic material because of health and safety hazards and possible odor and visual impacts. For example, Florida (FAC 2001) and North Carolina (NCAC 2007) regulations require that fill material not contain construction debris, toxic material or other foreign matter.

Selecting Native Material for Compatibility Analysis

If the project site has been impacted and it is difficult to determine what the native sediment consists of, a nearby, undisturbed site can be used when determining native sediment characteristics. The nearby site should have similar coastal processes and similar sediment type and range to be representative of what would originally have been at the impacted project site.

Nearshore Sediment Placement

Nearshore placement is an alternative to direct beach placement that can be implemented when cost or environmental impacts discourage placement directly on the beach, or when the sediment does not meet beach nourishment standards for the percentage of silt/clay sediment content. Nearshore placement of sediment dredged from coastal navigation channels (USACE 2010b) and from ebb- and flood-tidal deltas (Schupp et al. 2007) that is substantially free of contaminants is of growing interest for coastal managers, scientists, and residents. The common practice of placing dredged sediment far offshore removes sediment from the system and may contribute to long-term shoreline erosion on land adjacent to the channel (Morton 2008, Gailani and Smith 2006). Nearshore placement instead provides beneficial use of the dredged material and when applied properly, retains sediment within the littoral system.

Generally the success of nearshore placement in transporting sand to the beach decreases with increasing distance from shore (Smith et al. 2007). Regional and local sediment transport patterns must therefore be considered in the selection of placement sites in order for placed sand to benefit the littoral and beach sediment budget. Placement sites should also be chosen to minimize sand movement back into the navigation channel and to limit unwanted impacts to natural wave characteristics (Gailani and Smith 2006). Placement design should consider potential effects on nearshore biological populations and may require sampling and monitoring of biological resources in the nearshore as well as the intertidal areas. See the Project Design Considerations to Reduce Environmental Impacts and Monitoring Program sections for more information.

To our knowledge, Florida is the only state that regulates sediment properties for nearshore placement (Figure 7). Florida requires dredge material to have a maximum of 20% by weight of fines (passing a #230 sieve) for nearshore placement (FAC 2001). Projects in other states should consult with the lead coastal management agency in their state (see Appendix A).

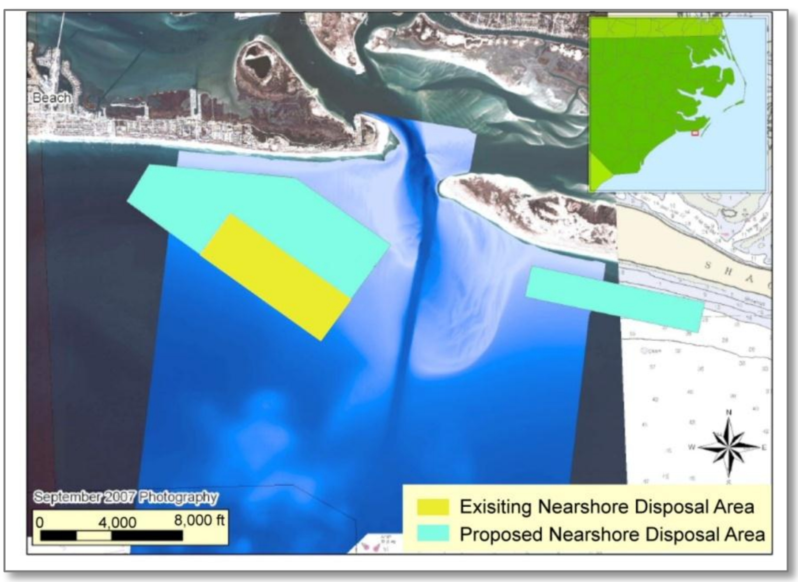

Figure 7. Map of existing and proposed nearshore placement areas at Beaufort Inlet, North Carolina. Shackleford Banks, a barrier island to the east of the inlet, is part of Cape Lookout National Seashore (Figure adapted from USACE 2010b).

Offshore Borrow Areas

Offshore areas are regularly used as the sediment borrow source for beach nourishment projects. Borrow material may be mined from ebb tidal shoals near inlets or shoals on the continental shelf, or reused from the creation or maintenance dredging of harbors, navigation channels, or waterways. Offshore borrow sources are generally evaluated through the collection of surface sediment samples, sub-bottom profiling and/or coring (Dean 2002). Sediment compatibility tests between the borrow and beach sediment, and analysis of the available borrow volume are required prior to dredging to ensure the sediment is of suitable quality and volume. The most important factor when considering suitability is grain size (see the Sediment Properties for Beach Nourishment section). Suitable borrow sediments are dredged from the seafloor and transported to the beach via dredges, barges, and/or pipelines.

In addition to sediment compatibility, evaluation of borrow sources should also consider the effects of dredging on wave transformation and sediment transport in the area. Pre- and post-dredging bathymetry should be simulated and used to investigate the possible effects of dredging a borrow area on littoral processes in the area (Gravens et al. 2008). The analysis should include a numerical wave model and comparison of breaking wave conditions, longshore transport rates, and transport rate gradients between pre- and post-dredging scenarios. If necessary, the depth or shape of the borrow area may require modification to avoid concentrations of wave energy or altered sediment transport (Gravens et al. 2008). Borrow areas should be in water depths greater than the zone of active sediment transport to avoid any reduction in cross-shore or alongshore sediment transport.

Borrow sites should be located away from important biological habitat such as significant spawning areas, Marine Protected Areas, or other habitats valuable to local fishery or benthic resources (Rice 2009). Excavation of the borrow site should avoid leaving large depressions or holes if possible, and instead employ a series of shallow, staggered cuts. This method allows the areas in between cuts to act as refugia for repopulation of benthic resources and limits alterations to the seafloor bathymetry (Rice 2009).

Dredging should also leave a sufficient layer of seafloor sediment that matches, as much as possible, the original surface layer to limit changes in habitat. For example, sediments within a borrow area off Folly Beach, South Carolina became increasingly fine (more silt/clay) after dredging and showed little evidence of recovery one year later (Bergquist et al. 2005). It was later determined that the borrow area filled with fine sediments because the area was dredged too deep (3 m below the seafloor) and was in close proximity to a harbor full of fine sediment (Bergquist et al. 2005). The biological community also changed after dredging, likely in response to the change in sediment.

Similar to the nourishment site, pre- and post-project monitoring of the borrow site is essential to identify any physical or biological change. Monitoring may include:

- Sediment sampling and analysis;
- Wave monitoring and modeling;
- Bathymetric and substrate surveys;
- Shoreline monitoring and modeling;
- Benthic community sampling and their trophic relationships to fishes; or
- Marine mammal and wildlife monitoring (during operations).

See Dean (2002), Greene (2002), Nairn et al. (2004), Gravens et al. (2008), and Rice (2009) for more information on borrow site evaluation, potential impacts of borrow dredging, and borrow site monitoring.

Project Design Considerations to Reduce Environmental Impacts

Every effort should be taken to avoid and/or mitigate impacts to NPS resources during beach nourishment projects. Projects should have clearly articulated objectives, preferably with quantitative goals that can be measured and monitored. These objectives should be related to, and informed by, the purpose and significance of the park unit. Careful attention must always be given to any threatened or endangered species. For example, an objective may be to “slow erosion on the seaward side of the fort while protecting native biota” or “restore and maintain 200 feet of beach habitat perpendicular to the shore for a length of 1 mile, for recreation and habitat protection.” This section includes specific design elements that may help to reduce negative impacts. It is important to note that beach nourishment can also have beneficial impacts on biota in the project area, many of which are well-adapted to naturally highly dynamic conditions that are typical of a beach and nearshore environment (Dean 2002).

Turbidity

The amount of turbidity in the nearshore environment due to sediment placement should be limited by following these best management practices:

- Use sediment that closely resembles native sediment;
- Select sediment with a low percentage of silt and clay;
- Limit the rate and total volume of placement;
- Use turbidity curtains to contain suspended solids; and
- Conduct fill placement when tidal elevation and wave energy is low.

High turbidity can impair filter feeding invertebrates, reduce light needed for photosynthesis, block the view of visual feeders, coat submerged aquatic vegetation, and be a deterrent to recreational use by the public (Greene 2002, Moffatt & Nichol 2006). Elevated sedimentation levels are also known to negatively influence coral reef communities and have been observed during beach nourishment activities (Jordan et al. 2010). Turbidity will usually disappear within several hours after operations finish, but some studies have shown turbidity to be a long-term problem (Greene 2002). Project managers should check with the lead coastal management agency in their state for any specific requirements (see Appendix A).

Placement Design

Placement Geometry

Placement geometry can have a significant influence on a project’s success and ecological impact. It is generally accepted that the elevation of the design berm should correspond to the natural berm crest elevation (Dean 2002, Gravens et al. 2008). Construction of a higher berm may produce a steeper beach face slope than natural and prevent turtles from crawling up the beach to nest (Steinitz et al. 1998) or degrade recreational use (Figure 8). Florida regulations, for example, require beach nourishment projects be designed to provide habitat that is suitable for successful marine

Figure 8. Excavator placing sediment along the Lake Michigan shoreline, Indiana Dunes National Lakeshore, Indiana (NPS photo).

turtle nesting activity (FAC 2001). If the design berm is lower than the natural berm, it may be overtopped and produce flooding and ponding on the berm (Gravens et al. 2008). An alternative design approach is to construct a berm that is slightly lower than the natural elevation and allow storms and overwash processes to build the elevation to the natural level (Dean 2002).

Design berm (beach) width depends on the purpose of the project, project economics, and environmental resources. For federal beach nourishment projects, berm width is calculated through a process of optimization based on storm damage reduction (Gravens et al. 2008). Beach width is optimized by computing the costs and benefits of different design options and choosing the option that maximizes net benefits (Gravens et al. 2008).

A key aspect of defining the design profile is to recognize if the pre-project beach has a healthy, normal profile shape or an unnatural shape. If the natural beach is sediment starved, profiles from nearby, healthy beaches that experience similar wave and tide conditions, and have similar grain sizes, can be used to determine the design profile. For federal projects the final design profile is determined through optimization. Storm-induced beach erosion modeling is performed during the optimization process to assess profile response from varied storm conditions. Different profiles are run through the model to find the option that provides maximum net economic benefits (Gravens et al. 2008).

During construction, the berm is built to the desired elevation, but it is often made much wider than the final design profile. The over-building method is used because of the working limitations of the equipment and the desire to place the material in the most economical way. Waves and current action will then redistribute the sediment to deeper parts of the profile over time (Gravens et al. 2008).

Figure 9. Proposed sand slurry pipeline at Gateway National Recreation Area, New Jersey. Sand would be removed from accreting Gunnison Beach and deposited in the eroding critical zone. Burial of biological resources is unlikely because only ~1530 m^3 (~2000 yd^3) of sand will be removed/filled per day (Figure from USFWS 2005).

Volume

The total volume of material placed is site-specific and based on the project goals, physical environment, infrastructure, potential downdrift effects, and sensitive biological resources. The volume required is calculated as the difference in cross-sectional area between the pre-project profile and the modified design profile shape (Gravens et al. 2008). The modified design profile shape is different than the design profile because it takes into account the amount of sediment needed to maintain the design profile prior to the first renourishment (see Gravens et al. 2008 for more information and examples). Differences in desired level of protection or potential for increased erosion may lead to alongshore differences in fill volume (Figure 9).

Placement of 4.1 million m^3 (5.4 million yd^3) of sediment on Perdido Key in Gulf Island National Seashore, for example, advanced the shoreline an average of 125 m (410 ft) seaward and caused unanticipated biological impacts (FDEP and Dean 2000). Monitoring showed the nourished beach was too wide for swash zone nutrients to reach vegetation in the back beach and ultimately caused a failure of sea oat seed production (per. communication R. Hoggard 2010). See the Perdido Key Case Study in Appendix C for more information.

Coverage

For beach nourishment projects, sediment is generally placed with a rectangular or trapezoidal planform along a continuous section of beach and the planform spreads out over time. Rice (2009) recommends that sediment should not be placed in one large area, but instead be divided up into smaller sections to leave undisturbed areas of existing biological resources. For this approach, future renourishment efforts should alternate which sections receive fill. Rice (2009) recommends individual sections not exceed 610 m (2000 ft) in length unless scientific monitoring proves otherwise. If possible, the beach fill should be spread in multiple layers and staggered over time in order to minimize invertebrate mortality and facilitate benthic invertebrate repopulation. Quite often, however, many nourishment projects deposit thick layers, resulting in high mortality of benthic macrofauna (Speybroeck et al. 2006).

Peterson et al. (2000) found a decrease of 86–99% in macro-invertebrate populations 5–10 weeks after nourishment. While the original organisms will die off, the newly restored beach should become naturally re-colonized. Recovery can sometimes be fairly quick (e.g. a few months to <1 year), because of rapid sediment dispersal and/or high natural species tolerance (Gorzelany and Nelson 1987, Nelson 1993, Smith and Rule 2001, Cruz-Motta and Collins 2004). However, when inappropriately selected sediments alter the native habitat characteristics, or have high organic or pollutant loads, the effects can be long lasting. Peterson et al. (2006) documented limited recovery of *Donax* spp. (coquina clam) 7–12 months after nourishment in North Carolina and a 70–90% decline in feeding shorebirds largely in response to prey depression of *Donax* spp. See the Minimizing Impact to Benthic Invertebrate Populations section for more information.

Nourishment activities should avoid sensitive habitats and areas with high ecological value. Projects should be scheduled to avoid productive biological seasons (see Project Timing section). If sensitive habitats exist within the project area buffers can be created. Rice (2009) recommends creating buffers of 100 m (328 ft) around wading bird colonies, 200 m (656 ft) around mixed tern/skimmer colonies, and 100– 200 m (328– 656 ft) around solitary bird nests. Sensitive plants should be given a buffer of at least 10 m (33 ft). If construction activities will occur 24 hours a day, 7 days a week, buffers may need to be greater. Sediment management projects in the nearshore and offshore environments should establish buffers around all reefs, hard bottoms, submerged aquatic vegetation, and other high value habitats. Rice (2009) suggests buffers be at least 500 m (1640 ft) around these habitats.

Compaction

Coastal nourishment projects should not increase sand compaction. Compaction can be limited by:

- Using compatible fill material with similar grain size, shape, calcium carbonate content, and silt/clay content as is found on the native beach;
- Staging and storing construction equipment off the beach; and
- Tilling the fill surface after placement.

Compaction affects water retention, permeability, exchange of gases and nutrients, and may decrease turtle nesting success by impeding nest excavation and preventing hatchling emergence (Milton et al. 1997, Steinitz et al. 1998, Defeo et al. 2009). In Florida, beach nourishment permits from the Florida Department of Environmental Planning require sand compaction to be 500 psi (pounds per square inch) or lower after nourishment (FAC 2001). However, some researchers argue that this threshold is unwarranted and needs to be revaluated (Davis et al. 1999). Projects in other states should check with the appropriate state agency for any compaction requirements (see Appendix A for a list of agencies).

Construction

Construction related traffic should be limited and controlled in order to minimize adverse impacts to air quality, habitat structure, traffic, public safety, noise, and biological processes including nesting and foraging. All associated vehicles and equipment should be muffled to limit disturbances to the fauna, such as shorebirds abandoning their nests. Project areas should also be clearly marked for safety concerns.

Project Timing

The acquisition of fill material and the construction phase of any project should be timed to avoid the most productive biological seasons, regular storm seasons, and high beach visitor-use times. Birds, sea turtles, fish, crabs, clams, amphipods, shrimp, worms, tiger beetles, and mysids are some of the animals that use the sandy intertidal area. The preferred timing for nourishment depends on the species inhabiting or exploiting the area and the nature and location of the project.

In areas that have nesting seabird and turtle populations, projects should not overlap with nesting seasons. For example, Florida discourages beach nourishment activities during the main portion of sea turtle nesting season (May 15 to October 31). The state of North Carolina also limits work from May 1 to November 15 to minimize adverse impacts to nesting sea turtles. In addition to nesting birds, timing of construction should also consider resting and foraging birds (Speybroeck et al. 2006).

Winter is the best season to minimize impact on epibenthic organisms and larger benthic infauna (Speybroeck et al. 2006). Nourishment during the warm season (beginning in April for the Atlantic coast) can affect macrobenthos reproduction, recruitment, and size (Peterson el al. 2000). For the Atlantic and Gulf coasts of the United States, winter (mid-November to February) is the best season for undertaking beach nourishment, partially because it avoids the spawning and recruitment periods for benthic invertebrates (Rice 2009).

The National Marine Fisheries Service (NMFS) and state regulations should be consulted regarding project timing if the project may impact essential fish habitat. If any threatened or endangered species habitat may be impacted, consultation with the United States Fish and Wildlife Service (USFWS) and NMFS is necessary to determine when (or if) sediment can be extracted and/or placed.

If possible, nourishment projects should avoid storm seasons, such as hurricane season (June 1 to November 30) in the Gulf States and nor'easter season (usually October thru April) in the Northeastern states. A major storm occurring during the construction phase could potentially transport a majority of the placed sediment from the project area.

Minimizing Impact to Benthic Invertebrate Populations

Native benthic invertebrates are protected under NPS *Management Policies* (NPS 2006) and the Organic Act (16 USC § 1). This section highlights ways to minimize impacts to benthic invertebrates because they are often present in beach and nearshore project sites. Other species that may be present, such as birds, fish, sea turtles, and clams, are equally as important and must be considered and addressed during pre-project planning.

To limit negative impacts to benthic invertebrates, projects should determine which populations are present and where they occur, and use compatible sediment (see the Sediment Properties for Beach Nourishment section). While sediment compatibility is widely considered key, impacts to invertebrate survival and recovery may also be reduced by:

- Conducting beach nourishment projects when invertebrate populations are at their seasonal low on the beach;
- Extending the time between renourishment episodes to permit recovery;
- Placing fill in several short sections (as opposed to a continuous section) to leave undisturbed regions for enhanced recovery;
- Limiting the volume and rate of sediment placement to allow motile invertebrates to migrate upwards; and
- Maintaining the natural beach profile to preserve habitat area.

(Peterson et al. 2000, Smith and Rule 2001, Greene 2002, Bishop et al. 2006, Peterson et al. 2006, Speybroeck et al. 2006, Defeo et al. 2009, Rice 2009, Vivian et al. 2009.) The rate of longshore transport may also play a role in benthic recovery because high rates of longshore transport have the capacity to dilute and disperse incompatible sediment and can enhance invertebrate immigration (Van Dolah et al. 1984, Peterson et al. 2006).

Figure 10. Ghost crab at Padre Island National Seashore, Texas (NPS photo).

Benthic macro-invertebrates, typically crabs (Figure 10), bivalve mollusks, amphipods, and polychaetes in warm oceans, are the prey base for surf fish, shorebirds, and epibenthic invertebrates (Greene 2002). Thus, they are critical to the health of higher trophic levels and can also serve as indicators of habitat for predator species. The effects of sediment placement (beach nourishment or nearshore sediment placement) on benthic invertebrates are diverse, ranging from few or no detectable effects (e.g. no measureable change in number of individuals or species richness in SE Australia; Smith and Rule 2001) to widespread, long-lasting impacts (e.g. decreased species richness and total density, and shifts in macrobenthic assemblage structure in Florida, Rakocinski et al. 1996). Most studies have found a significant decline in benthic invertebrate population at the placement location immediately following sediment placement due to burial and suffocation (e.g. Peterson et al. 2000, Cruz-Motta and Collins 2004, Bishop et al. 2006). However, the duration of the population impact varied by project. Studies show the most important determinant of impact and rate of recovery of benthic invertebrate populations is the degree to which fill sediment matches the native sediment (Nelson 1993, Peterson et al. 2000).

Previous research demonstrates that where fill sediment matches the native sediment (grain size distribution, mineralogy, organic content, and pollution loads) there are limited impacts on benthic invertebrate population abundances and recovery occurs fairly rapidly (between a few months to <1 year) (Gorzelany and Nelson 1987, Nelson 1993, Smith and Rule 2001, Cruz-Motta and Collins 2004).

Gorzelany and Nelson (1987) concluded that compatible fill material likely contributed to the lack of negative invertebrate effects at a beach nourishment project in eastern Florida. Similarly, the lack of detectable effects on the invertebrate community structure after nearshore sediment placement in Australia was attributed to compatible sediment and effective placement design (Smith and Rule 2001).

In contrast, other studies have found large depressions of benthic invertebrate populations where incompatible sediment was used (McLachlan 1996, Rakocinski et al. 1996, Peterson et al. 2000, Harvey et al. 1998, Peterson et al. 2006, Colosio et al. 2007). Peterson et al. (2006) reported that unnaturally coarse fill sediment during the winter 2001/02 Bogue Banks, North Carolina beach nourishment project was associated with limited benthic invertebrate recovery after one year and a 70–90% decline in feeding shorebirds, which they attributed to invertebrate prey depression. Rakocinski et al. (1996) also found delayed recovery of invertebrates in concert with increased silt/clay loading after a large beach and nearshore restoration project (7.1 million m^3 along 7 km of shoreline (9.3 million yd^3 along 4.3 miles)) in Gulf Islands National Seashore (see the case study in Appendix C).

Beach invertebrate populations are patchily distributed with densities of hundreds to thousands per square meter often occurring (McLachlan 1996). Intertidal invertebrate populations can also relocate during flood and ebb tides and with the normal deposition-erosion of shore sediments (Barnes and Wenner 1968). Although there is generally limited knowledge of invertebrate ecology, if possible, project managers should determine which populations are present and where they occur to protect invertebrate animals during beach nourishment projects. It may be possible to screen mobile invertebrate populations away from sediment discharge areas using block nets. Temporary removal and reseeding is also possible with many beach invertebrate populations.

In summary, a review of the scientific literature shows variable effects of sediment placement on benthic population survival and recovery based on the compatibility of the placed sediment, various design factors, and the natural physical processes occurring in the area. Utilizing fill sediment that closely matches the native sediment (e.g. grain size distribution, mineralogy, and organic content) appears to have the greatest influence. Effective project timing, design, and placement rate may also help to prevent negative impacts.

In 2007 the NPS Inventory and Monitoring Program (I&M) initiated a benthic habitat mapping program in ocean and coastal national parks. The report, A Servicewide Benthic Mapping Program for National Parks (USGS 2010) outlines the program's protocols and is a resource to learn more about benthic habitat mapping. NOAA's report, Guidance for Benthic Habitat Mapping: An Aerial Photographic Approach (NOAA 2001), may also be helpful if a project is using aerial photography for habitat mapping.

Monitoring Program

Beach nourishment projects should include scientifically rigorous pre-project, during construction, and post-project physical and biological monitoring. Monitoring is necessary to assess project performance, identify any impacts, and ensure project functionality and environmental standards. Monitoring provides critical information for adaptive management efforts (Rice 2009).

Monitoring plans will vary by project due to the project size, budget, species present, and overall monitoring goals. All monitoring plans must relate to the project objective, be scientifically based, and incorporate collaboration with various experts, including engineers, managers, and biologists. Larger projects should incorporate control areas and be statistically valid (Peterson and Bishop 2005). If possible, intersperse areas of nourishment and control sites to avoid spatial interdependence. Otherwise, bracket the nourished site with control sites on both sides (Peterson and Bishop 2005). For smaller projects, control areas may not be necessary if the goal is to just show whether or not project objectives have been achieved within the project area.

After a review of 46 beach monitoring studies, Peterson and Bishop (2005) concluded that many monitoring programs have serious flaws because they are conducted by contractors usually associated with the proponents of the project rather than by independent researchers, and have no independent peer-review. Instead, they suggest that monitoring programs should be carried out by a third/neutral party and include anonymous scientific peer-review. Data should also be shared with project managers and engineers in a timely manner to facilitate adaptive management (Rice 2009). Many of the monitoring aspects and components presented below are also applicable to monitoring of the borrow site. The NPS I&M Program has developed various monitoring protocols that can provide guidance for parks developing a monitoring program. All of the protocols are available on the I&M Monitoring Protocol Database (NPS 2012a).

Seasonality

Each characteristic or variable of a monitoring plan should have its own seasonal requirement, and therefore timing constraints, that should be identified and addressed in the monitoring plan. For example, because resource aspects (such as migratory bird use, hydrologic patterns, turtle nesting density, fish abundance, invertebrate abundance, and wave energy) change over various time scales, each should be assessed individually (Thayer et al. 2003). Both the project and control areas should be sampled each time sampling is conducted, and in the same month at a minimum. Annual monitoring should be done at the same time of year to reduce the effects of seasonality on detection of long-term trends.

Frequency

Monitoring should occur before, during, and after nourishment activities. Pre-project monitoring is required to obtain baseline data on significant flora and fauna in the area and to document the natural spatial and seasonal variability of the biological and physical systems (Gravens et al. 2008). These data can then be compared with data collected after restoration to assess any project related impacts. All relevant biological and physical variables should be sampled at the same time (or as close as possible) and sampling techniques must be consistent throughout the project to allow for hypothesis testing (Nelson 1993).

Duration

The duration of monitoring should vary by project depending on the project size, the variables being monitored, and overall monitoring goals. Pre-project monitoring should include enough time to gather baseline information on the preexisting systems. A pre-project sampling period of at least a year is highly recommended to observe storm events and seasonal patterns (Thayer et al. 2003). Monitoring during construction is critical to ensure that proper design specifications are met and should include periodic sampling of the fill material to catch any incompatible material (Thayer et al. 2003, Rice 2009). Post-construction monitoring should span a time period that permits statistical analysis.

Monitoring Components

Monitoring plans should contain one or more of the following components measured before the project is started (in order to establish a baseline), during construction, and for an appropriate length of time after the project is complete.

Figure 11. A federally-listed threatened and endangered species, a Piping plover (*Charadrius melodus*) chick, in Cape Cod National Seashore, Massachusetts. Beaches in the seashore serve as critical breeding habitat (NPS photo).

- Topographic surveys;
- Visual beach inspections;
- Beach sediment sampling;
- Turbidity monitoring;
- Aerial shoreline configuration (photography);
- Bathymetric surveys;
- Continuous wave and water-level measurements; and
- Biological monitoring of sea turtles, macro-invertebrates, birds, fish, seagrasses, corals, or other biological resources.

The physical characteristics, flora, and fauna monitored will vary by project. The project area may have highly sensitive areas such as sea turtle nesting sites or might include federally threatened and/or endangered species (Figure 11). Similarly, the physical conditions will differ widely between project sites, requiring different monitoring components. **It is not expected that every project will incorporate all of the monitoring activities listed below. The components are presented merely to show the activities that may be included in a monitoring plan.**

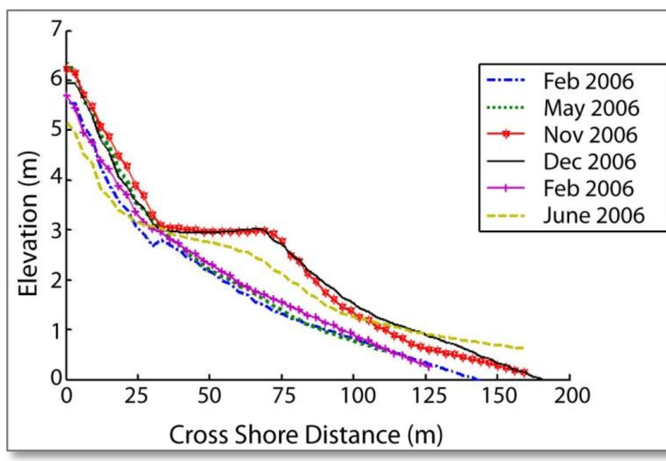

Figure 12. Beach profiles at Ocean Beach collected using an ATV-mounted GPS, Golden Gate National Recreation Area, California (Figure from Hansen).

Topographic Surveys

Topographic surveys are used to calculate and monitor beach volumes, monitor shoreline position, and to document changes in the beach cross section (Figure 12). Topographic data can be collected through profile surveys, all-terrain vehicle (ATV) mounted GPS surveys, or from airborne light-detection and ranging (LIDAR) surveys.

Profile surveys are accomplished by repeating profiles at regular intervals along the shoreline using traditional surveying techniques. Profile surveys should re-occupy the same transects every time and be referenced to a common baseline that is set at the beginning of the study (Gravens et al. 2008). Surveys should occur at low tide and cover the entire beach profile from the upper beach out to beyond the depth of closure (seaward limit of profile change). Annual surveys should be conducted during the time of year when wave energy is lowest. Since the distance between the profiles is usually large, the topographic data derived from profiling is spatially limited and the ability to make inferences about the beach as a whole is also limited.

Topographic surveys of the entire beach can be done using an ATV-mounted GPS receiver. The receiver collects position and elevation data at regular intervals (e.g. 1 sec) and then after the survey the georeferenced elevations are gridded to produce a three-dimensional surface of the beach. ATV surveys provide seamless, high-resolution topographic data for the entire beach. A typical survey of Ocean Beach (a 7 km (4.3 mi) long beach in Golden Gate National Recreation Area) consists of roughly 20,000 individual elevations (Hansen and Barnard 2010). The NPS Northeast Coastal and Barrier Network has developed an ATV ocean shoreline position monitoring protocol, which is available at http://science.nature.nps.gov/im/units/ncbn/vs/shoreline.aspx. ATV surveys may not be appropriate for all areas, particularly those with sensitive habitat or threatened species.

High-resolution elevation data can also be collected by airborne or stationary LIDAR (Gares et al. 2006). LIDAR measures distances by sending pulses of light that strike and reflect from the surface. The LIDAR system also measures the time of the pulse return and the GPS position, allowing it to record accurately georeferenced data. LIDAR generates very large point datasets that can be analyzed to provide highly accurate and detailed three-dimensional elevation models. More information about LIDAR is available online through NOAA's publication: Lidar 101: An Introduction to Lidar Technology, Data, and Applications (NOAA 2008).

Visual Beach Inspections

Visual inspections should occur concurrently with all baseline and post project monitoring events. If possible, conduct inspections at low tide to gather observations of the entire beach area. Inspections should note all observations about the condition of the beach (e.g. dune vegetation, storm scarping or overwash, post-storm recovery berms, sand bars, points and cusps, channels, longshore variability in beach features, sediment color, presence of shell hash, compaction, and slope). An observation checklist can be helpful to ensure consistent methods over time.

Sediment Samples

Sediment sampling is needed to determine any change in the grain size distribution over time, which could affect the beach shape and biological habitat. Sediment grab samples should be collected regularly along the profile survey lines and occur concurrently with annual profile surveys. Samples should re-occupy the same locations along the profile (e.g. berm, foreshore, cusp, foredune, etc.), include more than the surface layer of sediment, and be mixed well before analysis to ensure representative sampling of the beach.

Turbidity Monitoring

Turbidity monitoring should be conducted regularly during construction. Turbidity levels are often measured using a secchi disk that is mounted on a pole or line and lowered down in the water. The areal extent of increased turbidity can also be determined with digital photography (Moffatt & Nichol 2006). If monitoring indicates excessive, prolonged turbidity, construction should be halted or modified.

Best management practices for limiting turbidity should be employed including the use of compatible sediment with a low percentage of silt and clay, silt fencing to confine the suspended solids, and timing of the fill placement when tidal elevation and wave energy are low (see the Project Design Considerations to Reduce Environmental Impacts section for more information).

Aerial Photography

Vertical aerial photography is used to monitor long-term fill performance, shoreline position, and subaerial beach width (Gravens et al. 2008). Aerial photographs provide a total-project perspective that cannot be obtained with profile surveys alone and are an important resource for communicating with others. Vertical aerial photographs should be acquired at least annually and near midday around low tide to minimize shadows and capture the greatest area of beach (Gravens et al. 2008). Photographs should be taken just before the winter storm season and as close as possible to the date of the beach profile surveys. It is best to use the largest scale photography available, with 1:20,000 considered the smallest scale useable for shoreline mapping (Moore 2000). To perform any analysis of an image it must first be georeferenced (aligned to a map coordinate system).

Bathymetric Surveys

Bathymetric surveys are used to measure the bathymetry, or elevation, of the seafloor. Bathymetry can be measured using a single or multibeam echosounder system. An echosounder measures depth through use of sound signals emitted from an instrument mounted on a boat.

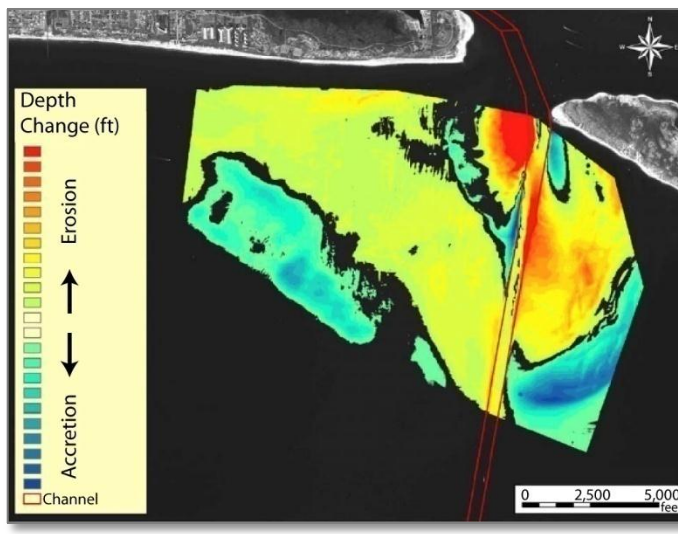

Figure 13. Bathymetric change from 1974–2009 at Beaufort Inlet, North Carolina, adjacent to Cape Lookout National Seashore (Figure adapted from USACE 2010a).

Shoreface profiles, offshore borrow sites, nearshore placement sites, and dredging sites can all be assessed and monitored through bathymetric surveying. Bathymetric data (Figure 13) can be used to find the depth of borrow sites (and whether the dredger can reach them), the surface area of sediment that is available to be dredged, the recharge rate of the dredged area, the shape of the shoals (which is important for fish habitat and wave attenuation), and bathymetric change over time. Data can also be used to model incoming waves and help to predict how wave energy may change if the bathymetry is modified. Bathymetric surveys are also important for capturing nearshore data to extend beach profiles offshore. Bathymetric profiles should align with the dry beach profiles and extend offshore some distance beyond the expected depth of closure.

Waves, Currents, and Water Level Measurements

Waves, currents, and water levels are measured because they are the primary hydrodynamic forces controlling beach evolution (Gravens et al. 2008). Wave, currents, and water level measurements should be taken before, during, and after the project. These data can be compared to measured beach response to help understand project behavior. Wave and water level measurements are often collected using a pressure gauge, buoy, or other sensor placed offshore of the project area.

Sea Turtle Monitoring

Figure 14. Kemp's ridley sea turtle (*Lepidochelys kempii*), a federally-listed endangered species, Padre Island National Seashore, Texas (NPS photo).

Sea turtle monitoring variables should be selected that will best reflect any change to their habitat that may occur as a result of the particular project (Figure 14). Most parks with sea turtle habitat have a turtle management program that can provide data necessary to evaluate pre- and post-project adverse or positive effects of a beach nourishment or modification project. The loggerhead sea turtle (*Caretta caretta*) and green sea turtle (*Chelonia mydas*) are federally-listed threatened and endangered species, respectively, and are regularly monitored during beach nourishment activities. Many different variables related to sea turtles have been monitored, including nest density, grain size distribution, sand moisture content, incubation period, hatching success, emerging success, hatchling fitness, clutch size, sand compaction, and sand temperature (Milton et al. 1997, Steinitz et al. 1998, Davis et al. 1999, Rumbold et al. 2001, Brock et al. 2009). Nesting density is often measured as part of monitoring programs and is determined by observing crawl tracks. Crawl tracks can also indicate the species and type of crawl (Rumbold et al. 2001).

Macro-Invertebrate Sampling

Macro-invertebrate species are sampled to characterize the ecological response of the beach after nourishment. These species are used because they capture the spatial distribution of perturbations due to their relatively sedentary nature and short life-cycles, and because they are an important component of the nearshore food web (Peterson et al. 2000). Macro-invertebrates can be sampled concurrently with sediment and beach profile sampling; however, the timing and frequency of invertebrate sampling should be designed to maximize the opportunity to capture representative population samples. A stratified sampling plan perpendicular to the shoreline, day and night sampling, and sampling during different tidal elevations may be appropriate because invertebrates (and other animals) respond to these environmental cues differently (Rudloe 1980, Peterson et al. 2006). Monitoring studies in North Carolina have studied mole crabs, coquina clams, and ghost crabs and have documented the effects of prey population changes on shorebird populations (Peterson et al. 2000, Peterson et al. 2006).

Coring is preferred over grab sampling because coring extends to the full depth of occupation of the sediment column, captures sedimentary strata, and includes the same amount of sediment per sample (Peterson and Bishop 2005). Ghost crabs can be monitored by counting active ghost crab burrow holes along the upper (mid-intertidal to dune crest) portion of beach profiles (Peterson et al. 2006). Lucrezi et al. (2009) found that several environmental factors significantly influence ghost crab burrow numbers and recommend that counts be limited to within a few hours after sunrise on days with low wind. See the Minimizing Impact to Benthic Invertebrate Populations section for more information on the effects of sediment placement on benthic invertebrates and actions to help reduce impacts.

Other Biological Resources

Other biological resources may require monitoring depending on the project and species present. Birds, fish, seagrasses, invertebrates, dune plants, and corals are just some of the resources that may be monitored. For example, projects in the Great Lakes may monitor the federally-listed threatened and endangered Piping plover (*Charadrius melodus*), while projects in the Northeastern U.S. may monitor the federally-listed threatened Northeastern Beach Tiger Beetle (*Cicindela dorsalis dorsalis*). Nearshore nourishment projects may monitor subtidal populations of invertebrates or fish that burrow and lay eggs in subtidal sands (e.g., sand lance and grunion).

Permits and Regulations

In addition to the NPS Organic Act, the key federal laws related to beach nourishment in units of the NPS are Section 404 of the Clean Water Act of 1972, the Rivers and Harbors Appropriation Act of 1899, and NEPA of 1970. NEPA requires the Federal Government to consider all reasonable alternatives before beginning any federal action. The analysis of alternatives is investigated through an Environmental Assessment or Environmental Impact Statement. Wetland and/or floodplain Statements of Finding may need to be attached to NEPA documents as required by NPS wetland protection and floodplain management procedures and as required by federal acts and Executive Orders (a representative list follows) and any state and county laws and permitting requirements that might apply. The NPS decision-maker must issue a written finding that the planned action will not lead to an impairment of park resources and values before proceeding. More information regarding the NEPA process can be found in the NPS Director's Order #12 and Handbook for Environmental Analysis, available online through the NPS Office of Policy (NPS 2012b). For information related to NPS jurisdiction see the Ocean and Coastal Park Jurisdiction Reference Manual #39-1 (NPS 2011).

Other federal laws and executive orders affecting coastal nourishment projects include, but are not limited to, the Endangered Species Act, Coastal Zone Management Act, National Historic Preservation Act, Clean Air Act, Fish and Wildlife Coordination Act, Land and Water Conservation Fund Act, Water Resources Development Act, Shore Protection Act, Coastal Barrier Improvement Act, Outer Continental Shelf Lands Act, Magnuson-Stevens Act, Marine Mammal Protection Act, Migratory Bird Treaty Act, Executive Order 13089: Coral Reef Protection, Executive Order 13158: Marine Protected Areas, Executive Order 11990: Protection of Wetlands, Executive Order 11988: Floodplain Management, and DOI Secretarial Order 3289: Climate Change.

The NPS Director's Order #12 Handbook lists 7 steps in a typical NEPA analysis process:

- Step 1: Identify your park's need for action;
- Step 2: Identify your park's goals and objectives in taking action;
- Step 3: Identify your proposal;
- Step 4: Identify issues or problems that need to be addressed to reach park goals and objectives;
- Step 5: Resolve these issues by creating reasonable alternatives;
- Step 6: Identify information gaps and needs and gather needed data; and
- Step 7: Identify the impacts of each alternative.

Communication with all affected agencies and stakeholders early and throughout the project is key for a smooth permitting process. For example, if a project will be interacting with the USFWS, it is recommended to contact the USFWS person who will ultimately be writing the response letter and discuss concerns they foresee related to the project. Early coordination with the Bureau of Ocean Energy Management is also important if outer continental shelf (OCS) sand or gravel will be mined (guidelines for obtaining resources from the OCS are available at http://www.boemre.gov/sandandgravel/PDF/MMSGuidelines/Final_MMS_Guidelines_120208.pdf). Public involvement is also a critical component of the process and is used as the basis for developing alternatives (NOAA 2010).

The NEPA process includes many details and key steps that cannot be missed. The NPS Office of Policy (NPS 2012b) webpage provides helpful documents under Director's Order #12, including the "Handbook for Environmental Impact Analysis" and "NEPA's 40 Most Asked Questions." Additional help with the NEPA process is available by contacting the planning and compliance staff in your region.

State and local regulations may also play an important role in coastal nourishment projects. Many states have specific beach nourishment requirements that must be taken into account when planning a beach nourishment project. Appendix A lists the lead coastal management agency for states containing a national park unit with ocean, coastal, or Great Lakes shoreline, as identified in Curdts (2011). Appendix A also includes a brief summary of some of the major regulations related to beach nourishment for each state.

The Coastal Zone Management Act (CZMA) of 1972 requires coastal states to develop and implement coastal zone management plans (CMPs). CMPs provide for the management of land and water uses that have a direct and significant impact on coastal resources. CMPs must be submitted to the Department of Commerce's NOAA for approval by the state. The CZMA requires federal agencies to conduct activities in a manner consistent with the state's federally approved coastal management program. If the project's state does have a federally approved program, a statement of consistency must be presented to the lead state agency by the federal project proponent to determine the project's consistency with the state's coastal management program prior to the beginning of the project. State coastal management program managers and federal consistency contacts for each state can be found online at http://coastalmanagement.noaa.gov/consistency/welcome.html.

A synopsis of state policies, laws, and regulations pertaining to beach nourishment, nearshore sand mining, dredge and fill operations, sand scraping/dune reshaping, dune creation/restoration, and public access is located in Appendix B of the *State, Territory, and Commonwealth Beach Nourishment Program, A National Overview* (NOAA 2000).

References

Avissar, N. G. 2006. Modeling Potential Impacts of Beach Replenishment on Horseshoe Crab Nesting Habitat Suitability. *Coastal Management* 34(4):427–441.

Barnes, N. B. and A. M. Wenner. 1968. Seasonal variation in the sand crab *Emerita analoga* (Decapoda, Hippidae) in the Santa Barbara area of California. *Limnology and Oceanography* 13(3):465–475.

Bergquist, D. C., S. Crowe, M. Levisen and R. F. Van Dolah. 2005. Change and Recovery of Physical and Biological Characteristics at Beach and Borrow Areas Impacted by the 2005 Folly Beach Renourishment Project. U.S. Army Corps of Engineers, Charleston District, Charleston, SC.

Bodge, K., S. C. Howard, and E. J. Olsen. 2006. Regional Sand Transport Study: Morehead City Harbor Federal Navigation Project. Olsen Associates, Inc., Carteret County, NC.

Brock, K. A., J. S. Reece, and L.M. Ehrhart. 2009. Effects of Beach Nourishment on Marine Turtles. *Restoration Ecology* 17(2):297–307.

Bishop, M. J., C. H. Peterson, H. C. Summerson, H. S. Lenihan, and J. H. Grabowski. 2006. Deposition and Long-Shore Transport of Dredge Spoils to Nourish Beaches: Impacts to Benthic Infauna of an Ebb-Tidal Delta. *Journal of Coastal Research* 223:530–546.

Browder, A. E. and R.G. Dean. 2000. Monitoring and Comparison to predictive models of the Perdido Key beach nourishment project, Florida, USA. *Coastal Engineering* 39:173–191.

Colosio, F., M. Abbiati, and L. Airoldi. 2007. Effects of Beach Nourishment on Sediments and Benthic Assemblages. *Marine Pollution Bulletin* 54:1197–1206.

Crain, D. A., A. B. Bolten, and K. A. Bjorndal. 1995. Effects of Beach Nourishment on Sea Turtles: Review and Research Initiatives. Restoration Ecology 3(2):95–104.

Cruz-Motta, J. J. and J. Collins. 2004. Effects of dredged material disposal on a tropical soft-bottom benthic assemblage. *Marine Pollution Bulletin* 48:270–280.

Curdts, T. 2011. Shoreline Length and Water Area in the Ocean, Coastal and Great Lakes Parks: Updated Statistics for Shoreline Miles and Water Acres. Natural Resource Data Series NPS/WASO/NRDS—2011/282. National Park Service, Fort Collins, Colorado.

Davis, R. A., M. V. FitzGerald, and J. Terry. 1999. Turtle Nesting on Adjacent Nourished Beaches with Different Construction Styles: Pinellas County Florida. *Journal of Coastal Research* 15:111–120.

Dean, R. G. 1974. Compatibility of Borrow Material for Beach Fill. Proceedings 14th International Conference on Coastal Engineering. Copenhagen, Denmark.

Dean, R. G. 1988. Recommendations for Placement of Dredged Sand on Perdido Key, Gulf Islands

National Seashore. Coastal and Oceanographic Engineering Department, University of Florida, Gainesville, FL.

Dean, R. G. 2002. Beach Nourishment: Theory and Practice. Advanced Series on Ocean Engineering, Vol. 18. World Scientific Publishing, Singapore, 399 pp.

Dean, R. G., E. Otay, and P. A. Work. 1995. Perdido Key beach nourishment project: A synthesis of findings and recommendations for future nourishments. UFL/COEL-95/011. Coastal and Oceanographic Engineering Department, University of Florida, Gainesville, Florida.

Defeo, O., A. McLachlan, D. S. Schoeman, T. A. Schlacher, J. Dugan, A. Jones, M. Astra, and F. Scapini. 2009. Threats to Sandy Beach Ecosystems: A Review. *Estuarine, Coastal and Shelf Science* 81:1–12.

Florida Administration Code (FAC). 2001. Rules and Procedures for Application for Coastal Construction Permits, Chapter 62B-41.

Florida Department of Environmental Protection (FDEP). 2010. Offshore Sand Search Guidelines.

Gailani, J. Z. and S. J. Smith. 2006. Numerical Modeling Studies Supporting Nearshore Placement of Dredged Material from the Savannah River Entrance Channel. U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, Mississippi.

Gares, P. A., Y. Wang, and S. A. White. 2006. Using LIDAR to Monitor a Beach Nourishment Project at Wrightsville Beach, North Carolina, USA. *Journal of Coastal Research* 22(5):1206–1219.

Gorzelany, J. F. and W. G. Nelson. 1987. The effects of beach replenishment on the benthos of a subtropical Florida beach. *Marine Environmental Research* 21:75–94.

Gravens, M., B. Ebersole, T. Walton, and R. Wise. 2008. Beach Fill Design. In: Coastal Engineering Manual, Part V, Coastal Project Planning and Design, Chapter IV-4, Engineer Manual 1110-2-1100, U.S. Army Corps of Engineers, Washington, D.C.

Greene, K. 2002. Beach Nourishment: A Review of the Biological and Physical Impacts. Atlantic States Marine Fisheries Commission, Washington, D.C. ASMFC Habitat Management Series no. 7.

Hansen, J. E. and P. L. Barnard. 2010. Sub-weekly to interannual variability of a high-energy shoreline. *Coastal Engineering* 57:959–972.

Harvey, M., D. Gauthier, and J. Munro. 1998. Temporal changes in the composition and abundance of the macro-benthic invertebrate communities at dredged material disposal sites in the Anse a Beaufils Bais des Chaleurs, Eastern Canada. *Marine Pollution Bulletin* 36:41–55.

Jordan, L. K. B., K. W. Banks, L. E. Fisher, B. K. Walker, and D. S. Gilliam. 2010. Elevated sedimentation on coral reefs adjacent to a beach nourishment project. *Marine Pollution Bulletin* 60:261–271.

King, D. and C. Galvin. 2002. Coastal Sediment Properties. In: Coastal Engineering Manual, Part III, Coastal Sediment Processes, Chapter I-1, Engineer Manual 1110-2-1100, U.S. Army Corps of Engineers, Washington, D.C.

Lucrezi, S., T. A. Schlacher, and S. Walker. 2009. Monitoring human impacts on sandy shore ecosystems: a test of ghost crabs (Ocypode spp.) as biological indicators on an urban beach. *Environmental Monitoring Assessment* 152:413–424.

McLachlan, A. 1996. Physical factors in benthic ecology: effects of changing sand particle size on beach fauna. *Marine Ecology Progress Ser*ies 131:205–217.

Milton, S. L., A. A. Schulman, and P. Lutz. 1997. The Effect of Beach Nourishment with Aragonite versus Silicate Sand on Beach Temperature and Loggerhead Sea Turtle Nesting Success. *Journal of Coastal Research* 13(3):904–915.

Moffat & Nichol. 2006. Final Sand Compatibility and Opportunistic Use Program Plan. Moffat & Nichol, Long Beach, California.

Moore, L. J. 2000. Shoreline Mapping Techniques. *Journal of Coastal Research* 16(1):111–124.

Morton, R.A. 2008. Historical Changes in the Mississippi Barrier Island Chain and the Roles of Extreme Storms, Sea Level, and Human Activities. Journal of Coastal Research 24(6):1587–1600.

Munsell Color. 2010. Munsell Color System; Color Matching from Munsell Color Company. Available from http://www.xrite.com/top_munsell.aspx (accessed 12 October 2010).

Nairn, R., J. A. Johnson, D. Hardin and J. Michel. 2004. A Biological and Physical Monitoring Program to Evaluate Long-term Impacts from Sand Dredging Operations in the United States Outer Continental Shelf. *Journal of Coastal Research* 20: 126–137.

National Oceanic and Atmospheric Administration (NOAA). 2000. State, Territory, and Commonwealth Beach Nourishment Program: A National Overview. Available from http://coastalmanagement.noaa.gov/resources/docs/finalbeach.pdf

National Oceanic and Atmospheric Administration (NOAA). 2001. Guidance for Benthic Habitat Mapping: An Aerial Photographic Approach. Available from http://www.csc.noaa.gov/digitalcoast/_/pdf/bhmguide.pdf

National Oceanic and Atmospheric Administration (NOAA). 2008. LIDAR 101: An Introduction to LIDAR Technology, Data, and Applications. Available from http://www.csc.noaa.gov/digitalcoast/_/pdf/What_is_Lidar.pdf

National Oceanic and Atmospheric Administration (NOAA). 2010. Beach Nourishment: A Guide for Local Government Officials. Available from http://www.csc.noaa.gov/beachnourishment/html/human/law/index.htm (accessed 20 October 2010).

National Park Service (NPS). 2006. *Management Policies*. U.S. Department of Interior, National Park Service, Washington, D.C.

National Park Service (NPS). 2011. Ocean and Coastal Park Jurisdiction Reference Manual #39-1. National Park Service, Lakewood, Colorado.

National Park Service (NPS). 2012a. Inventory and Monitoring Protocol Database. Available from http://science.nature.nps.gov/im/monitor/VitalSigns/BrowseProtocol.aspx

National Park Service (NPS). 2012b. National Park Service Office of Policy. Available from http://www.nps.gov/applications/npspolicy/index.cfm

National Park Service (NPS). 2012c. National Park Service Procedural Manual #77-1: Wetland Protection. National Park Service, Fort Collins, Colorado.

Nelson, W. G. 1993. Beach Restoration in the Southeastern US: Environmental Effects And Biological Monitoring. *Ocean and Coastal Management* 19:157–182.

North Carolina Administration Code (NCAC). 2007. Technical Standards for Beach Fill Projects, 15A NCAC 07H .0312.

Peterson, C. H., D. H. M. Hickerson, and G. G. Johnson. 2000. Short-term consequences of nourishment and bulldozing on the dominant large invertebrates of a sandy beach. *Journal of Coastal Research* 16:368–378.

Peterson, C. H. and M. J. Bishop. 2005. Assessing the Environmental Impacts of Beach Nourishment. *Bioscience* 5(10):887–896.

Peterson, C. H., M. J. Bishop, G. A. Johnson, L. M. D'Anna, and L. M. Manning. 2006. Exploiting Beach Filling as an Unaffordable Experiment: Benthic Intertidal Impacts Propagating Upwards to Shorebirds. *Journal of Experimental Marine Biology and Ecology* 338:205–221.

Rakocinski, C. F., R. W. Heard, S. E. LeCroy, J. A. McLelland, and T. Simons. 1996. Responses by macrobenthic assemblages to extensive beach restoration at Perdido Key, Florida, U.S.A. *Journal of Coastal Research* 12: 326–353.

Rice, T. M. 2009. Best Management Practices for Shoreline Stabilization to Avoid and Minimize Adverse Environmental Impacts. Prepared for the USFWS, Panama City Ecological Services Field Office.

Rudloe. A. 1980. The Breeding Behavior and Patterns of Movement of Horseshoe Crabs, Limulus polyphemus, in the Vicinity of Breeding Beaches in Apalachee Bay, Florida. *Estuaries* 3(3):177–183.

Rumbold, D. G., P. W. Davis, and C. Perretta. 2001. Estimating the effect of beach nourishment on Caretta caretta (loggerhead sea turtle) nesting. *Restoration Ecology* 9:304–310.

Schupp, C. A., G. P. Bass, and W. G. Grosskopf. 2007. Sand Bypassing Restores Natural Processes to Assateague Island, Maryland. Coastal Sediments Conference Proceedings, New Orleans, Louisiana.

Science Applications International Corporation. 2007. Draft Review of Biological Impacts Associated with Sediment Management and Protection of California Coastal Biota. Prepared for the California Coastal Sediment Management Workgroup, under contract with the Beacon Erosion Authority for Clean Oceans and Nourishment (BEACON).

Schumacher, B.A. 2002. Methods for the Determination of Total Organic Carbon (TOC) in soils and sediment. United States Environmental Protection Agency Environmental Sciences Division National Exposure Research Laboratory, Las Vegas, Nevada.

Smith, S. D. A. and M. J. Rule. 2001. The effects of dredge-spoil dumping on a shallow water soft-sediment community in the Solitary Islands Marine Park, NSW, Australia. *Marine Pollution Bulletin* 42:1040–1048.

Smith, S. J., J. Marsh, and T. Puckette. 2007. Analysis of Fluorescent Sediment Tracer for Evaluating Nearshore Placement of Dredged Material. U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, Mississippi.

Speybroeck, J., D. Bonte, W. Courtens, T. Gheskiere, P. Grootaert, J. Maelfait, M. Mathys, S. Proovst, K. Sabbe, E. W. M. Stienen, V. V. Lancker, M. Vincx, and S. Degraer. 2006. Beach nourishment: an ecologically sound coastal defense alternative? A review. *Aquatic Conservation: Marine and Freshwater Ecosystems* 16:419–435.

Steinitz, M. J., M. Salmon, and J. Wyneken. 1998. Beach Renourishment and Loggerhead Turtle Reproduction: A Seven-Year Study at Jupiter Island, Florida. *Journal of Coastal Research* 14(3): 1000–1013.

Thayer, G. W., T. A. McTigue, R. J. Bellmer, F. M. Burrows, D. H. Merkey, A. D. Nickens, S. J. Lozano, P. F. Gayaldo, P. J. Polmateer, and P.T. Pinit. 2003. Science-Based Restoration Monitoring of Coastal Habitats, Volume One: A Framework for Monitoring Plans Under the Estuaries and Clean Waters Act of 2000 (Public Law 160–457). NOAA Coastal Ocean Program Decision Analysis Series No. 23, Volume 1. NOAA National Centers for Coastal Ocean Science, Silver Spring, Maryland.

U.S. Army Corps of Engineers (USACE). 2010a. Environmental Assessment Mississippi Coastal Improvement Program – Barrier Island Restoration Plan, West Ship Island North Shore Restoration. U.S. Army Corps of Engineers, Mississippi Sound, Mississippi.

U.S. Army Corps of Engineers (USACE). 2010b. Morehead City Dredged Material Management Plan. U.S. Army Corps of Engineers, Wilmington, North Carolina.

U.S. Department of Commerce (USDOC), National Ocean and Atmospheric Administration. 2000. State, Territory, and Commonwealth Beach Nourishment Programs: A National Overview. National Ocean Service, Office of Ocean & Coastal Resource Management. Technical Document No. 00-01.

U.S. Environmental Protection Agency and United States Army Corps and Engineers (USEPA and USACE). 1998. Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. - Testing Manual, Inland Testing Manual. EPA reference 823-B-98-004, USACE Office of Water, Washington, D.C.

U.S. Fish and Wildlife Service (USFWS). 2005. Biological Opinion on the Effects of Construction and Operation of a Sand Slurry Pipeline System at the National Park Service, Sandy Hook Unit, Gateway National Recreation Area, Monmouth County, New Jersey on Piping Plover (*Charadrius melodus*), Seabeach Amaranth (*Amaranthus pumilus*), and Northeastern Beach Tiger Beetle (*Cicindea dorsalis dorsalis*). U.S. Fish and Wildlife Service, Pleasantville, New Jersey.

U.S. Geological Society (USGS). 2010. A Servicewide Benthic Mapping Program for National Parks. Available from http://pubs.usgs.gov/of/2010/1264/pdf/ofr2010-1264.pdf

Van Dolah, R. F., D. R. Calder, and D. M. Knott. 1984. Effects of Dredging and Open-Water Disposal on Benthic Macroinvertebrates in a South Carolina Estuary. *Estuaries* 7(1): 26–37.

Vivian, J. M., M. D. Domenico, and T. Cesear Marques de Almeida. 2009. Effects of dredged material disposal on benthic macrofauna near Itajai Harbor (Santa Catarina, South Brazil). *Ecological Engineering* 35: 1435–1443.

Work, P. A. and R. G. Dean. 1992. Perdido Key Beach Nourishment Project: Gulf Islands National Seashore 1991 annual Report.

Appendix A: State Beach Nourishment Policies

States listed in the table and in the following paragraphs are those that have a national park unit with ocean, coastal, or Great Lakes shoreline, as identified in Curdts (2011).

Table 4. Information sources for state beach nourishment policies. Table adapted from USDOC/NOAA (2000).

State	Lead Coastal Management Agency
Alaska	Dept. of Natural Resources, Alaska Coastal Management Program
American Samoa	Dept. of Commerce
California	Coastal Commission, San Francisco Bay Conservation and Development Commission, State Coastal Conservancy
Florida	Dept. of Environmental Protection
Georgia	Dept. of Natural Resources, Coastal Resources Division
Guam	Bureau of Statistics and Plans
Hawaii	Office of Planning and Office of Conservation and Coastal Lands
Indiana	Dept. of Natural Resources
Louisiana	Office of Coastal Protection and Restoration
Maine	State Planning Office
Maryland	Dept. of Natural Resources
Massachusetts	Executive Office of Environmental Affairs, Office of Coastal Zone Management
Michigan	Dept. of Natural Resources and Environment, Office of the Great Lakes
Minnesota	Dept. of Natural Resources
Mississippi	Dept. of Marine Resources
New Jersey	Dept. of Environmental Protection, Bureau of Coastal Engineering
New York	Dept. of Environmental Conservation
North Carolina	Dept. of Environment and Natural Resources, Division of Coastal Management
Ohio	Dept. of Natural Resources, Office of Coastal Management
Oregon	Dept. of Land Conservation and Development, Oregon Parks and Recreation Dept.
Puerto Rico	Dept. of Natural and Environmental Resources
South Carolina	Dept. of Health and Environmental Control, Ocean & Coastal Resource Management
Texas	General Land Office
Virgin Islands	Dept. of Planning and Natural Resources, Division of Coastal Zone Management
Virginia	Dept. of Environmental Quality
Washington	Dept. of Ecology
Wisconsin	Dept. of Administration, Bureau of Intergovernmental Relations

The following state policies are subject to change and may not be complete. More information was found for some states than others. States with limited information do not necessarily have fewer policies or requirements. States not listed may also have relevant policies. Please confirm all requirements with the appropriate state agency. Additional federal and/or local permits may also be required.

Alaska

The Alaska Department of Natural Resources oversees the Alaska Coastal Management Program. The Alaska Administration Code 112.200 states that placement of structures and the discharge of dredged or fill material into coastal waters must, at a minimum, comply with the standards contained in 33 CFR Parts 320–323 (the federal Navigation and Navigable Waters law). In addition to the statewide policies, some coastal districts also have enforceable policies related to beach nourishment and disposal of dredged material.

Alaska Coastal Management Program, Department of Natural Resources: http://alaskacoast.state.ak.us/

American Samoa

The Department of Commerce serves as the lead agency for the American Samoa Coastal Program. Land use permits are required for placing fill, dredging, or removing sediment from any coastal wetlands. Please contact the Department of Commerce for more information.

American Samoa Department of Commerce: http://www.doc.as/

California

The California Coastal Commission (CCC) is the lead agency responsible for carrying out California's Coastal Management Program by planning for and regulating development in the coastal zone consistent with the policies of the California Coastal Act. The CCC requires permits for any development within the coastal zone, broadly defined as the placement or erection of any solid material or structure, discharge or disposal of any dredged material; grading, removing, dredging, mining or extraction of any materials; or change of density of intensity of use of land. The San Francisco Bay Conservation and Development Commission is responsible for the San Francisco Bay-Delta portion of the coastal zone. In areas where there is a certified Local Coastal Program one must apply to that city or country directly.

California Coastal Commission: http://www.coastal.ca.gov/index.html

Florida

The Florida Department of Environmental Protection serves as the lead agency for the Florida Coastal Program. A Joint Coastal Permit is required to conduct any coastal construction activities. Florida has extensive eligibility criteria for coastal construction permits, including requirements related to marine turtle protection, design, siting, and sediment compatibility (see Table 1). Florida law requires that all sandy sediment excavated from the coastal system be deposited on the adjacent beach or in the nearshore. Monitoring programs are also required for any construction that is determined to have an adverse impact.

Florida Joint Coastal Permit Program: http://www.dep.state.fl.us/beaches/programs/envpermt.htm#JCP
Florida Rules and Procedures for Application for Coastal Construction Permits (PDF): https://www.flrules.org/gateway/ChapterHome.asp?Chapter=62B-41

Georgia
The Georgia Department of Natural Resources, Coastal Resources Division Coastal Management Program serves as the lead agency for the Georgia Coastal Program. A permit is required for all shoreline engineering activities and for all land alteration on beaches, sand dunes, and submerged lands. A permit will be issued only if the activity will not impair the values and functions of the natural system of sediment transport including the coastal sand dunes, beaches, sandbars, and shoals and if the activity is not contrary to the public interest. The Georgia Shore Protection Act outlines the permitting process and requirements for beach nourishment activities.

Georgia Department of Natural Resources, Coastal Resources Division: http://crd.dnr.state.ga.us/
Georgia Shore Protection Act: http://crd.dnr.state.ga.us/content/displaycontent.asp?txtDocument=84

Guam
The Bureau of Statistics and Plans oversees the Guam Coastal Management Program and the use, protection, and development within Guam's coastal zone. The Guam Territorial Seashore Protection Act requires a permit for any development (discharge of any dredged material or dredging, mining, or removal of any material) within a seashore reserve.

Guam Bureau of Statistics and Plans: http://www.bsp.guam.gov/

Hawaii
The Office of Conservation and Coastal Lands, within the Department of Land Natural Resources, is responsible for overseeing beach and marine lands out to the seaward extent of the state's jurisdiction. Permits are required for all beach nourishment activities and are broken into two categories. Category I includes projects less than 380 m^3 (500 yd^3) and Category II represents projects from 380–7,600 m^3 (500–10,000 yd^3). Projects greater than 7,600 m^3 (10,000 yd^3) require individual consultation with other agencies. All projects require sediment compatibility between the native and proposed fill material. Applications and beach nourishment guidelines are available on the Office of Conservation and Coastal Lands website.

Hawaii Office of Conservation and Coastal Lands: http://portal.ehawaii.gov/

Indiana
The Department of Natural Resources regulates beach nourishment in Indiana. Beach nourishment activities are encouraged through state statute to protect and increase sand in Indiana along Lake Michigan. A permit is required to place fill, erect a permanent structure, or remove material from a navigable waterway. Some projects may be eligible for a general permit. A royalty fee for the removal of materials dredged from Lake Michigan may be waived if any suitable material is placed along the Lake Michigan shoreline as beach nourishment for the beneficial use of the general public.

Indiana Department of Natural Resources: http://www.in.gov/dnr/

Louisiana

The Louisiana Department of Natural Resources, Office of Coastal Management (OCM) works to protect, develop, and restore or enhance the resources of the state's coastal zone. A Coastal Use Permit is required for projects that may impact coastal waters, including dredging or filling. The OCM requires beneficial use of dredged material wherever possible and has four options for permit applicants involved in coastal projects that include dredging:

1. Implementing a project that makes beneficial use of the dredged material;
2. Providing for the use of the dredged material on an approved coastal restoration project;
3. Using dredged material at another location that creates the same amount of beneficial use; or
4. Making a voluntary contribution to the Coastal Resources Trust fund, based on the amount of material dredged.

Louisiana Office of Coastal Management, Coastal Use Permit:
http://dnr.louisiana.gov/index.cfm?md=pagebuilder&tmp=home&pid=90&pnid=0&nid=189

Maine

The State Planning Office leads the Maine Coastal Program. Any dredging, bulldozing, or removing or displacing of material within the coastal sand dune system or coastal wetlands requires a Natural Resources Protection Act (NRPA) permit. The NRPA requires beach nourishment projects to use material that has texture and color characteristics consistent with the natural beach material. The profile of the new nourished beach must also be compatible with the natural beach profile and the timing of the project should minimize impacts on existing wildlife.

Maine Coastal Program, State Planning Office: http://www.maine.gov/spo/coastal/index.htm
Maine's Natural Resources Protection Act: http://www.maine.gov/dep/blwq/docstand/nrpapage.htm

Maryland

The Department of Natural Resources is the lead agency for Maryland's Chesapeake & Coastal Program. Maryland's coastal policies include the following beach nourishment requirements:

- The fill material grain size shall be equal to or greater in grain size and character to the existing beach material, or determined otherwise to be compatible with existing site conditions and acceptable to the Department;
- The fill material shall be relatively free of organic material, floating debris, or other objects;
- Silt and clay fills that change the sandy nature of the existing beach materials are not acceptable;
- Gravel fill may be acceptable, if particle sizes are equal to or greater than the existing beach materials; and
- Fill material shall be placed above the mean high water line before final grading to achieve the desired beach profile, unless site conditions prohibit the placement of fill material above the mean high water line and specific measures are designed to prevent material from washing away from the site.

Maryland Coastal Program, Department of Natural Resources: http://www.dnr.state.md.us/ccp/index.asp

Massachusetts

The Massachusetts Office of Coastal Zone Management (OCZM) serves as the lead agency for policy and technical assistance related to the Massachusetts Coastal Management Program. Proponents of beach nourishment projects are required to obtain a permit that includes characterizing beach conditions and stability and documenting the physical and chemical properties of the fill and native material. The Massachusetts Department of Environmental Protection and OCZM published a report detailing best management practices for beach nourishment projects in Massachusetts. By following the guidance proponents can expedite the permitting process. The report can be found online at: http://www.mass.gov/dep/water/resources/bchbod.pdf

Massachusetts Office of Coastal Zone Management: http://www.mass.gov/czm/czm.htm

Michigan

The Office of the Great Lakes, within the Department of Natural Resources and Environment, administrates Michigan's Coastal Management Program. The Shorelands Protection and Management section of the Natural Resources and Environmental Protection Act is the key state statute regarding coastal erosion and the environmental protection of coastal areas. Permits are required for dredging, filling, grading, or placement of permanent structures in designated environmental areas.

Michigan Coastal Management Program: http://www.michigan.gov/deq/0,1607,7-135-3313_3677_3696---,00.html
Michigan Shorelands Protection and Management Permit:
http://michigan.gov/statelicensesearch/0,1607,7-180-24786_24825-244641--,00.html

Minnesota

The Department of Natural Resources (DNR) manages Minnesota's Lake Superior Coastal Program. One goal of the DNR it to limit the use of beach sand and other types of fill in order to prevent damage to fish spawning areas, aquatic habitat, and water quality of Minnesota's lakes. For most projects constructed below the ordinary high-water level of public waters, an individual Public Waters Work Permit is required.

Minnesota's Lake Superior Coastal Program: http://www.dnr.state.mn.us/waters/lakesuperior/index.html

Mississippi

The Mississippi Department of Marine Resources serves as the lead authoritative agency for activities in the coastal zone. Permits are required for any dredging or filling activities and fill material must be non-toxic and either stabilized or of sufficient size as to not be displaced during typical storm tides.

Mississippi Department of Marine Resources: http://www.dmr.state.ms.us/

New Jersey

The Bureau of Coastal Engineering, operating under the Office of Engineering and Construction and the Department of Environmental Protection, is responsible for administering beach nourishment, shore protection and coastal dredging projects throughout New Jersey. New Jersey regulates nourishment as a non-structural shoreline protection measure. Uncontaminated dredged sediments with 75% sand or greater are generally encouraged for beach nourishment (NJ Admin. Code 7:7E-4.8).
N.J. Admin Code 7:7E-7.11. Beach nourishment projects, such as non-structural shore protection measures are encouraged, provided that:

1. The particle size and type of fill material is compatible with the existing beach material to

ensure that the new material will not be removed to a greater extent than the existing material would be by normal tidal fluctuations;
2. The elevation, width, slope and form of proposed beach nourishment projects are compatible with the characteristics of the existing beach;
3. The sediment deposition will not cause unacceptable shoaling in downdrift inlets and navigation channels; and
4. Public access to the nourished beach is provided in cases where public funds are used to complete the project.

New Jersey Bureau of Coastal Engineering: http://www.nj.gov/dep/shoreprotection/
New Jersey Administration Code (PDF): http://www.state.nj.us/dep/landuse/7-7e.pdf

New York
The Department of Environmental Conservation administers a Coastal Erosion Control Permit Program that regulates beach restoration activities. In addition, the Department of State is in charge of the Coastal Zone Management Policy and determining federal consistency. The following standards must be met for permit issuance:

- Is reasonable and necessary, considering reasonable alternatives to the proposed activity, and the extent which the proposed activity requires a shoreline location;
- Will not be likely to cause a measurable increase in erosion at the proposed site or other locations; and
- Prevents, if possible, or minimizes adverse effects on:
    - Natural protective features and their functions and protective values;
    - Existing erosion protection structures; and
    - Natural resources including, but not limited to, significant fish and wildlife habitats and shellfish beds.

New York Department of Environmental Conservation, Coastal Erosion Control Permit Program: http://www.dec.ny.gov/permits/6064.html
New York State Coastal Policies: http://www.nyswaterfronts.com/consistency_coastalpolicies.asp

North Carolina
The North Carolina Department of Environment and Natural Resources, Division of Coastal Management implements and supervises coastal zone management programs. North Carolina has extensive regulations regarding beach nourishment and requires a Coastal Area Management Act permit. Beach restoration, sand nourishment and disposal projects may be allowed when (15A North Carolina Administration Code 07M.0202):

1. Erosion threatens to degrade public beaches and to damage public and private properties;
2. Beach restoration, nourishment or sand disposal projects are determined to be socially and economically feasible and cause no significant adverse environmental impacts;
3. The project is determined to be consistent with state policies for shoreline erosion response and state use standards for Ocean Hazards, Public Trust Waters, Areas of Environmental Concern and the relevant rules and guidelines of state and federal review agencies.

The code also states that clean, beach quality material dredged from navigation channels within the active near shore, beach or inlet shoal systems must not be removed permanently from the active near shore, beach or inlet shoal system unless no practical alternative exists. Preferably, this dredged material will be disposed of on the ocean beach or shallow active nearshore area where environmentally acceptable and compatible with other uses of the beach (15A NCAC 07M.1101). North Carolina has detailed, quantitative requirements regarding sediment compatibility (see Table 1) and sampling techniques.

North Carolina Department of Environment and Natural Resources, Division of Coastal Management Permits: http://dcm2.enr.state.nc.us/Permits/aecs.htm
North Carolina Administration Code: http://ncrules.state.nc.us/ncac.asp

Ohio
The Ohio Department of Natural Resources, Office of Coastal Management implements the Ohio Coastal Management Program. A Shore Structure Permit is required before undertaking construction of an erosion, wave, or flood control structure along the Lake Erie shoreline in Ohio. Shore structures include beach nourishment, seawalls, groins, breakwaters, and more.

Ohio Department of Natural Resources, Office of Coastal Management Shore Structure Permits:
http://www.ohiodnr.com/Ohio_Coast/RegulatoryHome/ShoreStructureGuide2/tabid/9287/Default.aspx

Oregon
The Oregon Department of Land Conservation and Development serves as the lead agency for the Oregon Coastal Program. Oregon's ocean shore is managed by the Oregon Parks and Recreation Department, which has an extensive permitting program for shoreline protection under The Ocean Shore Law. A permit is required for any improvement made within the ocean shore. An improvement is defined as filling, removing material, or constructing on the ocean shore. The ocean shore is defined as the land lying between the extreme low tide of the Pacific Ocean and the statutory vegetation line or the line of established upland shore vegetation, whichever is farther inland.

Oregon Coastal Management Program: http://www.oregon.gov/lcd/ocmp/
Oregon Ocean Shores Permitting, Oregon Parks and Recreation Department:
http://www.oregon.gov/OPRD/RULES/index.shtml

Puerto Rico
The Department of Natural and Environmental Resources (DNER) manages the maritime zone, coastal waters, and submerged lands and serves as the lead agency for Puerto Rico's Coastal Program. Please check with the DNER for any required permits.

Puerto Rico Coastal Management Program, Department of Natural and Environmental Resources:
http://www.drna.gobierno.pr/oficinas/arn/recursosvivientes/costasreservasrefugios/pmzc/coastal-zone-management-program

South Carolina
The Department of Health and Environmental Control, Ocean & Coastal Resource Management protects and enhances South Carolina's coastal resources. A permit is required for any land disturbing activity in coastal waters, tidelands, beaches, or the beach/dune system. The Beachfront Management Act policies severely restrict the use of hard erosion control devices and encourage the replacement of hard erosion

control devices with soft technologies that will provide for the protection of the shoreline without long-term adverse effects.

South Carolina Department of Health and Environmental Control, Ocean & Coastal Resource Management: http://www.scdhec.gov/environment/ocrm/

Texas

The Texas General Land Office is the designated lead coastal management agency. A permit is required for any construction within 305 m (1,000 ft) landward from mean high tide and is issued by local governments in conjunction with the Land Office.

Texas General Land Office, Caring for the Coast: http://www.glo.texas.gov/what-we-do/caring-for-the-coast/index.html

Virgin Islands

The U.S. Virgin Islands Coastal Zone Management is managed and administered by the Division of Coastal Zone Management, located within the Department of Planning & Natural Resources. A Coastal Zone Management permit is required for any development activity along the coast, excluding all federal land, offshore islands, and cays. The permit system is divided into major and minor permits, with the distinction being how much effect the project will have on the coastal environment and community.

Virgin Islands Division of Coastal Zone Management: http://coastal-zone-management.dpnr.gov.vi/

Virginia

The Virginia Coastal Zone Management Program is comprised of a network of state agencies and local governments with authority in the coastal zone. The Department of Environmental Quality serves as the lead agency. Any shoreline stabilization project, including riprap, bulkheads, breakwaters, beach nourishment, groins, or jetties require a Joint Permit. The Joint Permit Application is used to apply for permits from the Local Wetlands Boards, Virginia Marine Resources Commission, Department of Environmental Quality, and the U.S. Army Corps of Engineers.

Virginia Coastal Zone Management Program:
http://www.deq.state.va.us/Programs/CoastalZoneManagement.aspx

Washington

The Washington State Department of Ecology is the lead coastal management agency. Washington's Shoreline Management Act establishes a local/state partnership in administering permits. All shoreline permits are processed by the local government and then sent to Ecology for approval. Permits are required for any development within the shorelines of the state. Development consists of construction of structures, dredging, filling, dumping, and removal of any sand, gravel, or minerals. Substantial development permits are required for any development where the total cost exceeds five thousand dollars or the development interferes with the normal public use of the water or shorelines of the state.

Washington Coastal Zone Management, Washington State Department of Ecology:
http://www.ecy.wa.gov/programs/sea/czm/index.html

Washington Shoreline Permit System:
http://www.ecy.wa.gov/programs/sea/sma/st_guide/administration/intro.html

Wisconsin
The Wisconsin Coastal Management Program is administered by the Department of Administration, Bureau of Intergovernmental Relations. Chapter 30 of the Wisconsin Statues includes dredge and fill regulations. Please contact the Coastal Management Program to learn about permits and requirements.

Wisconsin Coastal Management, Bureau of Intergovernmental Relations:
http://www.doa.state.wi.us/category.asp?linkcatid=648&linkid=65&locid=9

Appendix B: Case Study – North End Restoration Project, Assateague Island National Seashore, MD

Project Description

Since its construction in 1935, a jetty system at Ocean City Inlet has caused unnatural sediment deprivation on northern Assateague Island, Maryland, thereby lowering island elevation, accelerating the natural shoreline erosion rate (Figure 15), and causing associated habitat degradation. To mitigate impacts of the loss of natural sand transport processes, local and national government agencies created a comprehensive two-phase restoration plan.

Figure 15. Aerial image looking south showing Ocean City Inlet and eroded Assateague Island at the top of the image (Photograph by Jane Thomas, IAN Image Library; www.ian.umces.edu/imagelibrary)

The first short-term phase of the comprehensive restoration plan occurred in 2002; this one-time beach nourishment widened the beach by 30 m (98 ft) over a distance of 10.5 km (6.5 mi) by replacing about 15% (1.4 million m^3 or 1.8 million yd^3) of the sand captured by the inlet since 1934 (Figure 16). Additionally, a low foredune was constructed along the 2.4 kilometer-long (1.5 mi) area most vulnerable to overwash as a temporary measure to prevent imminent island breaching and the consequences that a breach would have on the island, the populated mainland, and inlet hydrodynamics.

The second phase, which began in January 2004, addressed the source of the problem, sediment starvation, by restoring sediment transport to the nearshore area of the North End through biannual mechanical bypassing of a sediment volume approximately equal to the natural pre-inlet longshore transport rate (144,000 m^3/yr or 188,000 yd^3/yr). This phase is planned to continue for 25 years. A hopper dredge places the majority of sediment about 80–250 m (262–820 ft) from the high water shoreline in depths of -1.5 to -5 m (-5 to -16 ft) (NAVD88), on the crest and just seaward of the nearshore bar.

Measures of Project Success

Quantitative metrics were identified and used to evaluate the overall performance of the project and to identify if and when established threshold conditions for project modification were met:

- Volume of sand mechanically bypassed (to show that the volume was equal to a natural pre-inlet rate of sediment transport);
- Shoreline change rate (to determine whether the management intervention achieved the desired goal of shoreline erosion slowing to a natural pre-inlet rate of change);

- Success and population size of piping plover, a federally-listed threatened and endangered bird species (one indicator of a healthy early-succession beach habitat);
- Percent area of sparse vegetation (a second indicator of healthy early-succession beach habitat)
- Changes in the elevation of the constructed foredune (significant growth or decline would indicate the need for further intervention); and
- Frequency and extent of overwash events across the foredune (less than three events per year would indicate that the foredune was acting as an unnatural barrier), with consideration given to wave and wind conditions and the behavior of the surrounding areas of the North End.

Additionally, although it was not established as a project metric, the nearshore volumetric change is regularly calculated in order to determine how much of the bypassed sand is reaching the shoreline.

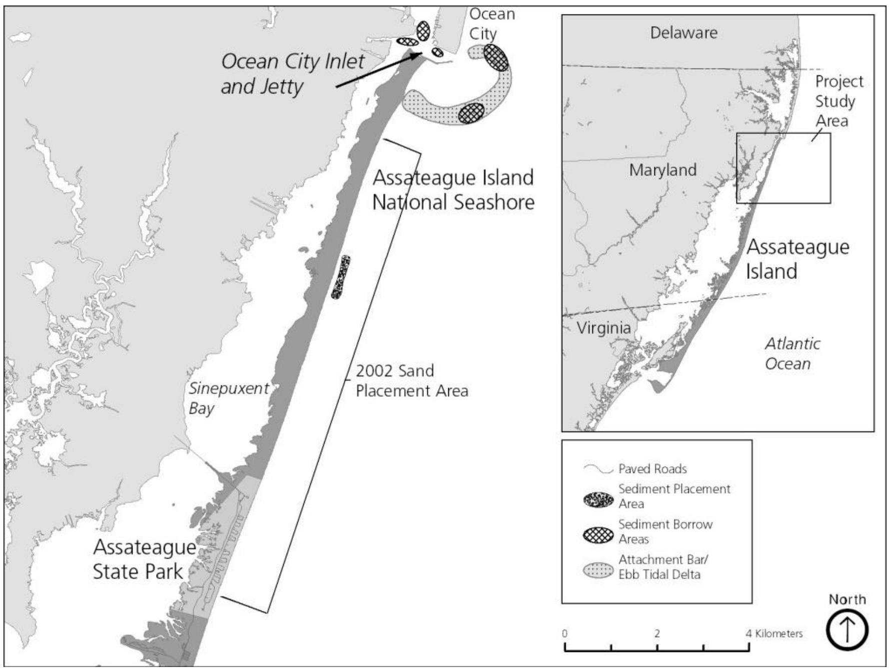

Figure 16. Location map of the North End Restoration Project, Assateague Island National Seashore, MD (Figure from Schupp et al. 2007).

Monitoring Program

Many of the datasets needed to evaluate the project were already being collected by existing park monitoring programs. Pre-construction and post-construction monitoring surveys of the project area measured these characteristics:

- Topographic and volumetric change: lidar (as available) and cross-island topographic profiles spaced at 0.5 km (0.3 mi) intervals (twice yearly);
- Shoreline response: high water shoreline position (quarterly);
- Occurrence of plant communities (associations): observation of stratified random sampling points, in particular to calculate area of sparse vegetation (annually);

- Piping plover reproductive success: number of breeding pairs, nest attempts, chicks hatched, chicks fledged (annually);
- Nearshore bathymetry: bathymetric profiles extending from the upper beachface to the depth of closure (annually) and swath bathymetry of the tidal deltas and within depth of closure (as available); and
- Meteorological conditions: Remote automated weather stations on Assateague Island National Seashore (ASIS) (hourly wind speed and direction, precipitation, temperature), USACE nearshore wave gauge (hourly significant wave height, period, and direction), and NOAA tidal station (water level).

Lessons Learned: Potential Pitfalls

Several unexpected and undesirable outcomes resulted from decisions made in the planning and implementation phases:

Placement Location

Although the project was intended to slow the shoreline erosion rate to approximately -1.5 m/yr (± 1.7 m/yr) (4.9 ft/yr ± 5.6 ft/yr), analysis of the shoreline position data indicated that directly onshore of the target placement site the shoreline had actually begun accreting at a rate of up to 10 m/yr (33 ft/yr) over the first three years of mechanical bypassing (Figure 17). This shoreline change rate was unnaturally high and therefore undesirable. The bypassed sand had been expected to move alongshore due to wave action, but the calm weather conditions (measured by the nearshore wave gauge and on-island weather station) likely led to its relative immobility. To correct this condition, the target placement area was extended to the north and south of the initial target area in order to distribute the sand more widely until stronger weather conditions prevailed.

Sediment Size Distribution

Although the dredge material targeted for foredune construction had a sediment size distribution similar to the native beach material, the sediment that was eventually placed on the island had a larger proportion of coarse-grained materials, including gravel, than the native sediment. The wind carried away the smaller particles and left the coarser (gravel) sediments as a lag surface, which limits the underlying sediments ability to be moved during wind and storm events and also influences nest site selection of piping plover.

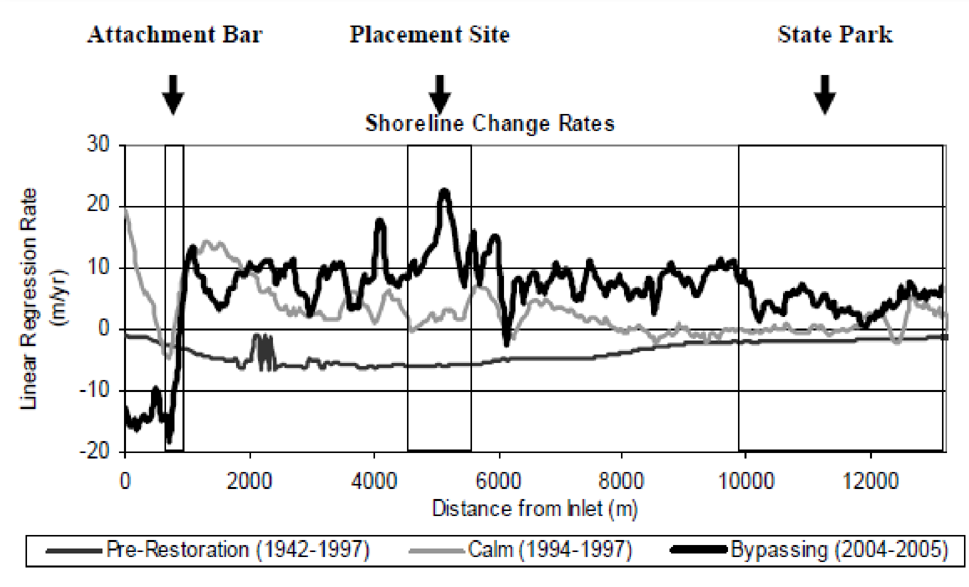

Figure 17. Monitoring data illustrated that the shoreline section directly onshore of the sediment placement site became highly and unnaturally accretional, signaling the need for a change in placement site at ASIS (Figure from Schupp et al. 2007).

Model Parameters

The dimensions of the nourished beach and the temporary foredune, which was built to prevent breaching in the short period before the long-term mechanical bypassing phase could begin, were modeled with the assumption that the recent erosion rates and storm frequency were representative of the years to come. Instead, weather conditions were much calmer after the foredune was built, and ASIS did not experience major storm impacts for 10 years following construction. As a result, the beach in front of the foredune did not erode as quickly as expected, and the design height and setback of the constructed foredune prevented overwash along the project's entire length (2.4 km/1.5 mi), while the surrounding portions of the North End experienced overwash. The foredune also grew in volume, maintained its height, and sheltered the island interior from wind and waves. This fostered succession from sparsely vegetated habitat to an increasing area of herbaceous vegetation, shrub communities, and the associated growth of embryo dunes due to the sand-trapping effects of the increased vegetation (Figure 18).

Figure 18. Unexpected conditions led to a loss of overwash processes and a sheltered island interior at ASIS, fostering vegetation succession and dune growth (NPS photo).

The monitoring program enabled ASIS to identify and quantify these undesirable changes in ecosystem function, and to clearly and convincingly communicate to cautious partners that there was a pressing need for action. NPS and project partners are now mitigating these conditions by notching the foredune to allow overwash, by discussing appropriate placement sites before every mechanical bypassing cycle, and by continuing to analyze monitoring data to identify any other undesirable conditions that may arise.

Lessons Learned: Success Stories

Many methods selected for this project appear to have been the correct choice for minimizing undesirable impacts to visitors and the ecosystem.

Placement Timing

Mechanical bypassing is scheduled for early spring (February to March) and late fall (October) to minimize potential conflicts with high recreational use (June to August), piping plover breeding season (April to August), and northeaster storms (November to February).

Mechanical Bypassing Method

In order to minimize impacts to the beach ecosystem, it was preferable to place sand in the shallow nearshore area instead of directly onto the beach. The dredge vessel (Figure 19) carries about 350 m^3 (460 yd^3), and varies the specific dump location, so the total volume bypassed is dispersed in time and distance; therefore, any one load is unlikely to impact benthic communities through heavy burial. This method is significantly different than traditional beach nourishment projects that place large volumes of sand directly onto the beach and then often redistribute the sand with heavy equipment; those methods create significant change in short periods of time, and can bury and crush invertebrate communities.

Figure 19. A hopper dredge placing sediment on and just seaward of the nearshore bar at ASIS. Waves and currents move the sediment onto the shoreline (NPS photo).

Importance of Long-Term Monitoring

By evaluating the monitoring data on a regular basis, undesirable conditions and trends have been detected. Management actions to rectify these undesirable results have included notching the foredune to allow overwash, changing the sediment placement site, changing the amount of sediment dredged, rescheduling surveys in order to capture appropriate data, and identifying new needs for data and modeling.

Appendix C: Case Study – Perdido Key, FL in Gulf Islands National Seashore

Figure 20. Perdido Key Beach in Gulf Islands National Seashore, Florida (NPS photo).

Project Description

The eastern end of Perdido Key (Figure 20), a barrier island in Gulf Islands National Seashore, Florida (Figure 21), has experienced long-term erosion (Dean 1988), primarily due to the interruption of littoral drift caused by maintenance dredging of Pensacola Pass. To dispose of dredged material from a deepening project at Pensacola Pass and counteract shoreline erosion, the U.S. Army Corps of Engineers initiated a large, two-phase beach and profile nourishment project at Perdido Key from 1989 to 1991. The amount of acceptable quality material available for beach placement was determined from vibracores. Grain size, visual evidence, and color information were compiled for each core to assess sediment quality.

Figure 21. Location map of Perdido Key, Gulf Islands National Seashore, Florida.

The first phase of restoration included onshore placement of roughly 4.1 million m^3 (5.4 million yd^3) of material along 7.5 km of shoreline (5.4 million yd^3 along 4.7 mi) from November 1989 to September 1990. The second phase included offshore placement of an additional 3 million m^3 (3.9 million yd^3) of material in water depths of roughly 6 m (20 ft) from November 1990 to September 1991 (Rakocinski et al. 1996).

Monitoring Program

The monitoring program began in 1989 with a pre-construction survey of the project area and adjacent shorelines. After the nourishment project, surveys were conducted on an annual or biennial basis. Physical monitoring included beach profile surveys (Figure 22), bathymetric surveys of the offshore portion of the profiles and of the offshore placement area, wave, tide, and current measurements, and meteorological data collection (Browder and Dean 2000). As part of the project the Navy agreed to a 5-year monitoring plan that included:

- Geophysical studies to determine behavior of the placed material and develop a predictive model;
- Vegetation monitoring to determine patterns of revegetation;
- Effects of the new sand on undisturbed habitats;

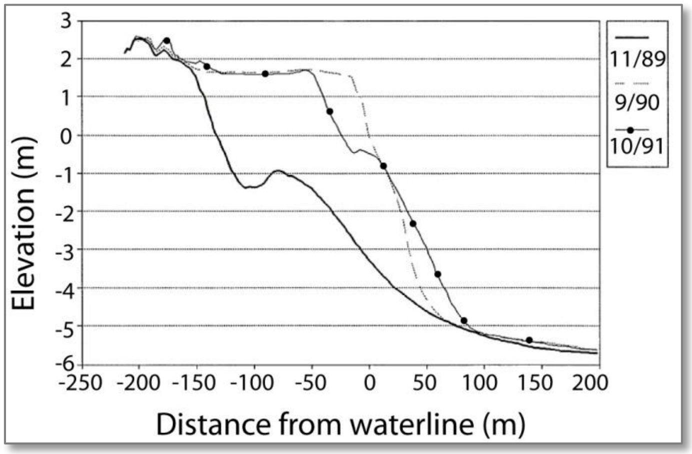

Figure 22. Average profiles (based on 7 profiles) within the nourishment area, Gulf Islands National Seashore, Florida (Figure from Work and Dean 1992).

- Similarity of the new beach to the old in terms of vegetation composition;
- Perdido Key beach mouse (*Peromyscus polionotus trissyllepsis*) ecology monitoring to examine mouse population biology and response to habitat alteration;
- Benthic community studies to determine composition of benthic communities short-term effects of placed material, and rates of recovery; and
- Ecosystem synthesis to integrate and interpret the above studies into a whole-system framework for management.

Lesson Learned from Monitoring: Beach Width

The nourishment project advanced the shoreline an average of 125 m (410 ft) seaward (Browder and Dean 2000). Post-construction monitoring determined that this was too wide to allow sufficient nutrients from the swash zone to reach the vegetation resulting in a production failure of sea oat seeds (per. communication R. Hoggard 2010). These seeds are vital to the survival of the endangered beach mouse on Perdido Key. A reduction in the beach mouse population was documented in the nourishment area; however, a study conducted by Sankaran 1993 concluded that this was a result of the initial population size being below the critical level required and not necessarily related to the beach nourishment (Dean 2002).

Monitoring for Future Nourishment Projects

Recommendations for future monitoring efforts at Perdido Key include the following studies:

- Sea turtle nesting/hatching surveys and nest relocation;
- Visual escarpment surveys (before turtle season and routinely during the season) and follow-up inspections;
- Piping plover surveys of bayside and Gulf beaches (bi-monthly from July 15 through May 15 every year for 10 years);
- Perdido Key beach mouse tracking surveys;
- Sediment dynamics and island morphology (fate of sediments);
- Effects on sea oat production and other island vegetation;
- Benthic recruitment following placement; and
- Success of littoral zone placement.

Design Considerations for Future Projects at Perdido Key

Littoral Zone Placement

Post-nourishment studies by Dean et al. (1995) concluded that sediment placed deeper than 3.7 m (12 ft) will not move back onto the shore if it is outside the outer bar. It is therefore recommended to place sediment on the beach or in the nearshore zone inside the outer sand bar to keep sediment in the littoral zone.

Mid-island Placement

The NPS intent of receiving dredged material is to restore sediment to the littoral system, not to just anchor the island in place. Previously, material was only placed along the eroding eastern shoreline. Future placement at Perdido Key should consider mid-island and north beach placement as well.

Seasonal Timing

Dredging and sediment placement have a significant potential to impact the animal communities on and around the island if the placement activities are not timed correctly to avoid periods of high animal activity. In order to avoid substantial biological disturbances, as well as to the visiting public, placement activities should be limited to the months of November through February.

Federally listed threatened and/or endangered species present in the project area include:

- Loggerhead sea turtle (*Caretta caretta*),
- Green sea turtle (*Chelonia mydas*),
- Leatherback sea turtle (*Dermochelys coriacea*),
- Kemp's ridley sea turtle (*Lepidochelys kempii*),
- Piping plover (*Charadrius melodus*),
- Least tern (*Sterna antillarum*),
- Gulf sturgeon (*Acipenser oxyrinchus desotoi*),
- Perdido Key beach mouse (*Peromyscus polionotus trissyllepsis*), and
- West Indian manatee (*Trichechus manatus latirostris*).

Beach Configuration

The final beach configuration after nourishment has significant influence on the recovery and function of the barrier island. Future beach nourishment at Perdido Key should follow the recommendations outlined by Dean et al. (1995), including:

- Placement of sediments over a short beach length with tapered ends;
- Shoreline length to be based on a placement density from 175 to 213 m^3 per meter of beach (70 to 85 yd^3 per foot);
- Limit placement volumes to 382,000 m^3 (500,000 yd^3) or less: and
- Limit shoreline advance to no more than 61 m (200 ft).

Future beach configuration at Perdido Key should also include compatible slopes for nesting sea turtles, beach widths conducive to beach mouse productivity and success, varying berm elevation to allow overwash to penetrate the back beach, placements to be in alternate segments to support benthic repopulation, and reduced renourishment volumes to reduce impacts.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 909/114346, September 2012

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov